Festivals and Sustainability: Reducing energy related greenhouse gas emissions at music festivals

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Given the focus of this work I feel it's worth highlighting those in the music industry who, over the course of my research, helped remind me of the benefits of the industry whilst I studied its costs. These include, but are by no means limited to, Into It Over It, Koji, Polar Bear Club, Frank Turner, The Gaslight Anthem, Alexisonfire, New Found Glory, The Wonder Years, Banquet Records, Tom Beck of Walnut Tree Records, Mark Gadong of Everything Sucks, Richard Heaven of PFC, and everyone connected to Some Dudes of Nottingham.

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"Now who'd've thought that after all, something as simple as rock 'n' roll would save us all?"
Frank Turner

Abstract

This thesis investigates the potential to reduce greenhouse gas emissions relating to electrical power provision at UK music festivals. It has been carried out in partnership with a number of UK festival organisers and power providers.

The thesis provides a literature review of sustainable event management and the associated electrical power provision, before then investigating the existing methodologies for quantifying greenhouse gas emissions at festivals. This review identified a lack of data regarding energy demand at events other than total fuel demand. While energy data does not improve the accuracy of GHG accounting, it provides more detail which can identify opportunities to reduce these emissions.

Data was gathered from 73 power systems at 18 music festivals from 2009-2012. This produced typical festival power load profiles for different system types including stages, traders and site infrastructure. These load profiles were characterised using a series of indicators that can create performance benchmarks, in addition to increasing the detail of carbon auditing.

Analysis of the load profiles identifies opportunities for emission reduction. These address either the supply or demand for power in order to reduce on site fuel consumption. These opportunities include changes in operating procedure to reduce demand during non-operational periods, utilising low energy equipment on stages, and using a power provision system capable of adjusting power plant supply to meet demand.

The work has documented power demand at festivals, and highlighted opportunities for change that can reduce costs and emissions, as well as informing festivals on their practices.

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Equations

Abbreviations

A/V – Audio/visual or audio/video

AEME – Association for Events Management Education

AGF – A Greener Festival

AIF – Association of Independent Festivals

BAFA – British Arts & Festivals Association

BUC – Baseload uniformity coefficient

CIRET – Centre International de Recherches et d'Etudes Touristiques

CO_2 – Carbon dioxide

CO_2e – Carbon dioxide equivalent

DECC – Department of Energy and Climate Change

DEFRA – Department for Environment, Food and Rural Affairs

DMH – De Montfort Hall

DMU – De Montfort University

FOH – Front of house

FR – Festival Republic

FYE – Face Your Elephant

GFA – Green Festival Alliance

GHG – Green house gas

IF – Impact factor

IESD – Institute of Energy and Sustainable Development

IPCC – International Panel on Climate Change

JB – Julies Bicycle

kWh – Kilowatt hour

LED – Light emitting diode

LF – Load factor

M&T – Monitoring and targeting

M&V – Measurement and verification

MF – Modulation factor

PDUC – Peak demand uniformity coefficient

PF – Power factor

PV – Photovoltaic

RET – Renewable energy technology

RMS – Root mean square

T&D – Transmission and distribution

TRET – Temporary renewable energy technology

UK – United Kingdom

VA – Volt Amps

WVO – Waste vegetable oil

Chapter 1 – Introduction

1.1 Background

It is widely acknowledged that there is a need for worldwide reductions in greenhouse gas emissions in order to prevent anthropogenic climate change as a result of human activity (IPCC, 2001; IPCC, 2007). In order to do its part in mitigating climate change, the UK has committed to an ambitious 80% reduction in carbon emissions in relation to UK CO_2 emissions by 2050 when compared with the nations emissions in 1990, with a reduction of at least 34% by 2020 (Climate Change Act, 2008; DECC 2009 [1,2]).If these targets are to be met, significant reductions will be necessary across all industries. This thesis examines the opportunities for emission reductions in the music festival industry.

At the beginning of the 21st century, the UK festival industry experienced a boom period (Youngs, 2010). Nearly 1,000 festivals take place each year within the UK (Efestivals, 2012), and these events cover a variety of types of music festival; indoor and outdoor, one-day or multi-day, urban or greenfield, 100 person capacity or 100,000 person capacity, winter or summer. The popular image of a festival however is the outdoor summer festival, far away from urban spaces, attended by thousands of people camping in nearby fields for a number of days. The majority of festivals investigated in this thesis fall under this description.

This boom coincided with an increase in awareness and in media publications for climate change, as well as similar topics such as sustainable development and corporate social responsibility (Boykoff et al, 2007; Anderson, 2008). Like other sectors, the music industry as a whole began to study its environmental impact, with organisations forming in order to share best practice and calculate the associated carbon emissions, as well as organisers and artists auditing their own operations (Stentiford, 2007; Harper 2008). This research estimated that festival audience travel and power provision accounted for 77,000 tonnes of carbon dioxide equivalent (CO_2e) in 2008. While this is only 0.012% of the UK's emissions in 2008, they accounted for 19.5% of the emissions for the UK live music industry (Bottrill, 2008; DECC, 2010), and can be seen to be a significant source of emissions within the industry. It should be noted that emissions resulting from waste material have not been considered in these totals.

To put these figures into context, of the 77,000 tonnes CO_2e attributed to festival audience travel and power provision, 20,000 tonnes were from on-site power generators operating primarily on diesel fuel, and are the second largest source of emissions other than audience car travel.

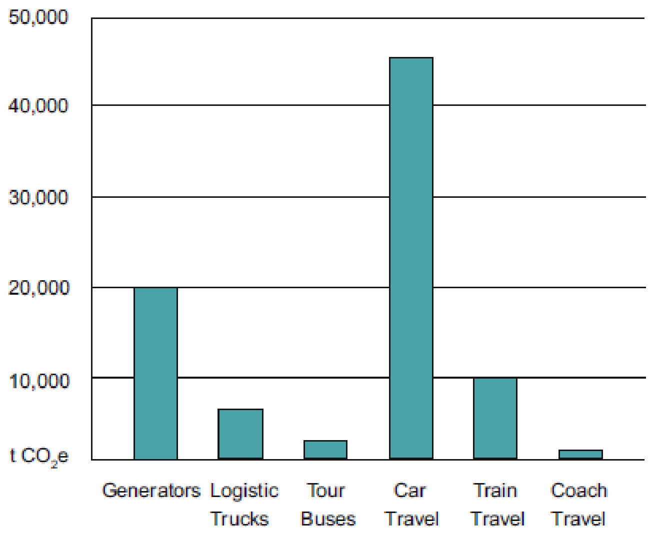

Figure 1 - Total greenhouse gas emissions from festivals per annum by activity source, t CO_2e (Bottrill, 2008)

Much of the research until this point has been conducted in order to determine the current state of a festivals environmental impact and associated greenhouse gas emissions, with little progress beyond establishing a baseline for each event. This situation appears ready to change soon with conferences and seminars being created to facilitate knowledge sharing between individual organisers and others interested in the field (Challis, 2013a, 2013b; Green Events Europe, 2012). Academically however there has been little published regarding analysis of festival greenhouse gas emissions, particularly with a view to electricity related emissions. Audience travel and on site waste have been the primary sources of investigation given the managerial problems they create, such as traffic management concerns, local resident complaints, and site cleanup requirements. On site power provision has only very briefly been examined, with no research probing deeper than calculating the total on site diesel use (Baker, 2011; Bottrill 2008; Harper 2008; Tsiarta & Heathfield, 2011). In response, the following research objectives were formed with the overarching research aim to investigate the nature of greenhouse gas emissions from power provision at festival sites.

1.2 Research objectives

Objective 1: Assess the current methodologies used to calculate a festivals carbon footprint.

In order to accurately determine the relevance of this research, the methodological constructs used to analyse the carbon footprint and greenhouse gas emissions of festivals must be established. As this field is still in its infancy, with much of the necessary data being estimated or generalised, there may be scope to improve the accuracy of carbon footprint reporting.

Objective 2: Use short time interval measurements to analyse power consumption of festival subsystems.

Analysis of power consumption at festivals through short time interval measurements has not previously been conducted. The technique is widely used to assess energy performance of the built environment, so its applicability to a different environment will be of great interest. This interest lies in the novel data itself, as well as the potential for a new methodology for analysing GHG emissions at music festivals.

Objective 3: Identify potential strategies for the reduction of GHG emissions from power provision at music festivals.

The data obtained by fulfilling objectives one and two will be used to suggest areas for improvement within the industry, along with identifying potential barriers to change.

Through meeting these objectives, this thesis aims to make a novel and original contribution to knowledge. It will provide festival organisers, sustainability officers and power providers with a new way to analyse their power usage and the associated carbon footprint, as well as outlining potential improvements.

1.3 Scope of the research

The aim of the research is to understand power use on a festival site, with a view to reducing the greenhouse gas emissions associated with this process. From early in the research process, it was apparent that this research would be conducted using a number of case studies. Initially a sector wide study was considered, however this was rejected on the grounds that this would be too large a scope for a research topic aiming to look at power systems in greater detail than any previous work. At any one time the researcher could only potentially measure up to ten systems, and given that many festivals would run simultaneously during the summer period, the practicalities of collecting data on an industry wide basis were deemed to be insurmountable. The potential work of other researchers was also considered. For the duration of the research, Julies Bicycle continued to publish new material and investigate new avenues of research (Baker, 2011) which have been able to complement the research presented in this thesis.

The primary data collected was current demand in time intervals varying from 30 seconds to 30 minute intervals, with the majority at intervals of 60 seconds. This data was collected through non-invasive techniques using current transformers to record current demand in specific systems over the course of the festival.

Primary data collection comprised of short time interval, high resolution electrical current recordings collected using a variety of brands of current clamps and dataloggers (equipment specifications can be found in section 4.1.1), which were typically installed on the Wednesday and uninstalled on the Monday. In many situations these targets were not adhered to due to the subsystem subject to monitoring not arriving or being configured in time for Wednesday, or were disconnected prior to Monday.

Data collection of this kind at a festival represents unique working circumstances. Music festivals are temporary events that typically will take place over the course of one weekend in a location that may not usually host such an event. An entire community, and associated infrastructure, must be constructed in a temporary environment so that it may function for up to six to seven days whilst the public is on site. Staff will be under stress to organise and carry out the construction, operation, and subsequent deconstruction of a site, and will be working constantly. As a result the research was designed to allow for flexibility with the production crew, and to work to their schedule without compromising the quantity or quality of data recorded.

This thesis includes data gathered at 18 different events over 7 different festivals from 2009-2012. The initial festivals studied were chosen on the basis of existing relationships that organisers had established with De Montfort University (DMU). In recent years DMU has crafted working relationships with both De Montfort Hall (DMH) and Festival Republic (FR). De Montfort Hall is a 2,200 person capacity venue located in Leicester City Centre, and has hosted both comedy and music festivals in recent years, as well as concerts, plays and graduation ceremonies. Festival Republic is responsible for four greenfield festivals in England, and has an expanding roster of international festivals. Both of these organisations were working with DMU for the Face Your Elephant (FYE) project prior to start of this research. FYE was a research project organised by Paul Fleming and Christopher Maughan from DMU to engage festival goers in the science and engineering of how they can reduce their personal carbon footprint, and was carried out in conjunction with DMH & FR (Fleming & Maughan, 2009). It is through this relationship that the researcher was able to have direct access to the festival organisers to discuss using their events as case studies. Additional festivals were added to the study on the strength of the researcher's relationship with festival organisers and through dissemination of findings throughout the research. For a list of systems monitored, see appendix C.

Other factors considered included the festivals location and target demographic, the economic and political stability of the event, and the success of the festival. These are all factors that will influence a festival, and while they may mean a festival must operate in a different manner than they would otherwise, they were not deemed to be factors that were necessary to vary when examining power consumption at a festival. Further discussion regarding the decisions behind the festivals chosen and the subsystems examined can be found in chapter 4. A summary of the data collected can be found in table 1.

Festival size	Capacity	Location	Years monitored	Number of datasets collected	Festival key designators
Small	2,300	Urban	2	6	A, E
Medium	7,000	Urban	4	12	C, G, K, P
Large	35,000	Greenfield	4	20	B, F, I, N
Major	70,000	Greenfield	4	21	D, H, L, Q
Large	35,000	Greenfield	1	3	J
Medium	9,000	Greenfield	2	4	M, R
Medium	15,000	Greenfield	1	7	O

Table 1 - Summary information for festivals studied

1.4 Thesis structure

This thesis consists of eight chapters, the remainder of which are summarised below

Chapter 2: Literature review

Discusses the recent history of festivals and reviews the existing literature regarding sustainability at such events. This covers both peer-reviewed literature and industry examples in order to establish the state of the industry prior to this research.

Chapter 3: Carbon footprints at festivals

Describes the methodological approaches taken by others in this field. The merits and drawbacks of each method are discussed, before focussing on the gaps in knowledge regarding electricity use at festivals that are shared between the methodologies. Based on this review, a methodology is tested in order to address this gap in knowledge. The chapter addresses research objective one.

Chapter 4: Research and data acquisition methodology

Describes the methodological approach to the research as a whole, as well as the practicalities of data collection at festival sites. Conceptual and practical considerations are examined, and potential obstacles to the approach are listed along with the impact they may have upon the research.

Chapter 5: Data analysis methodology

This chapter presents the techniques that are used to analyse power use at music festivals in each individual system. The core of this is a series of statistics that are adapted from similar metrics used in energy analysis techniques in the built environment. These statistics are designed to be used to characterise energy use at festivals, and are subsequently used as benchmarks in chapter 6.

Chapter 6: Load profile results

Presents and analyses the short time interval power consumption of festival subsystems, specifically stages, traders, campsites and assorted other infrastructure systems. This chapter focuses on the relaying of information, determining the usefulness of each of the metrics presented in chapter 5,and describing specific case studies that exhibit noteworthy consumption that can be used to identify opportunities for energy reduction. This chapter addresses research objective two.

Chapter 7: Discussion

Uses the findings of chapter 6 to discuss the viability of strategies designed to decrease the carbon footprint of music festivals. This chapter addresses research objective three.

Chapter 8: Conclusions

Summary of the research as a whole. The findings of the work are placed into context with the sector as a whole, along with future work that may arise as a result of the thesis.

The conclusions are followed by the list of references and appendices.

Chapter 2 – Literature Review

Introduction

This chapter presents a review of relevant background literature. Firstly the definitions of ‘festivals’ and ‘sustainability’ are established, before moving on to discuss relevant peer-reviewed literature in the field of event management, as well as practical examples of sustainable practices and initiatives already undertaken by festivals and events. The purpose of this chapter is to describe the existing baseline of knowledge in the field, before moving on to an examination of existing carbon footprint methodologies in chapter three.

2.1 Defining ‘festivals’ and ‘sustainability’

This thesis examines the sustainability of music festivals and their associated carbon emissions resulting from electrical power provision. In order to do this, the concepts of a music festival and sustainability must be defined. Beginning with sustainability, Brundtland (1987) defines sustainable development as:

> ***”Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"***
>
> ***Gro Harlem Brundtland (1987)***

This definition is often cited as being the clearest available definition of sustainable development, and sustainability. Judging sustainable development based on its constituent words, it relates to the development of a system, either so that the system is developing in sustainable manner, or developing towards a being a sustainable system.

The key concept of the Brundtland definition is to ensure that activities and processes undertaken in the present will not have a negative impact on the potential of future generations to carry out their own activities. The quote can be examined from many different perspectives, ranging from large global goals, such as mitigating anthropogenic climate change, to smaller goals for individuals, such as starting a family. If these goals are met through using a sustainable process, or the goal itself is a sustainable system, then the system as a whole will have developed in a sustainable manner.

In order to determine whether a process or system is sustainable however, the relevant resources must be examined to determine whether the development is causing these resources to be depleted. A model frequently used to describe sustainable development is the three pillars or three circles model (Adams, 2006) which is an adaptation of the triple bottom line (TBL) model (Pope, Annandale & Morrison-Saunders, 2004; Brown, Dillard & Marshal, 2006). The overriding theme through them all is that the economic, environmental and social impacts of a process must all be considered, not just as a series of cumulative figures with respect to the TBL, but also with respect to the concerns of festival stakeholders e.g. the social implications for a festival organiser, the financial implications for the audience, etc.

Classically, the 'bottom line' is in reference to the economic bottom line, quantified through a series of accounts in terms of a unit of currency. For the environmental bottom line, a bottom line expressed in terms of finance is not appropriate. It is instead expressed in terms of the mass of greenhouse gas emissions (GHG) in terms of kg or tonnes CO_2 equivalent (CO_2e). CO_2e is a term used to express the total volume of GHGs without needing to separate them into their constituent gases, such as carbon dioxide, methane and nitrous oxide (Bernstein et al, 2007). IPCC studies propose that these emissions are a factor in anthropogenic climate change, as successive studies have shown increases in average global temperature, with more than 90% probability that this is due to increased GHG emissions (IPCC, 2007). The IPCC goes on to state that as a result of changing global temperatures, the Earth's climatic systems will change as well, putting the Earth's current biosphere at risk from a more hostile climate and further rises in temperature (IPCC, 2001). In line with these studies, the international community is working to reduce global GHG emissions by committing to agreements such as the Kyoto Protocol.

The Kyoto Protocol is an international agreement created in response to the threat of a changing biosphere. It commits participating countries to mitigate climate change through the reduction of GHG emissions (UNFCCC, 2012). These targets vary from region to region based upon each nation's own emissions. Currently the EU is committed to GHG emission reductions of 20% by 2020, relative to their emissions in 1990 (European Commission, 2009), and the UK has committed itself to reductions of 34% by 2020 and 80% by 2050 (DECC, 2009). The fulfilment of these commitments will require emission reductions from every industrial sector in the country, including the music industry.

In 2007 the UK GHG emissions have been calculated to be 518 million tonnes (AEA, 2010), of which 540,000 tonnes were attributed to the music industry, equating to 0.1% of the total national emissions (Bottrill et al, 2008). These music industry emissions are broken down further in figure 2.

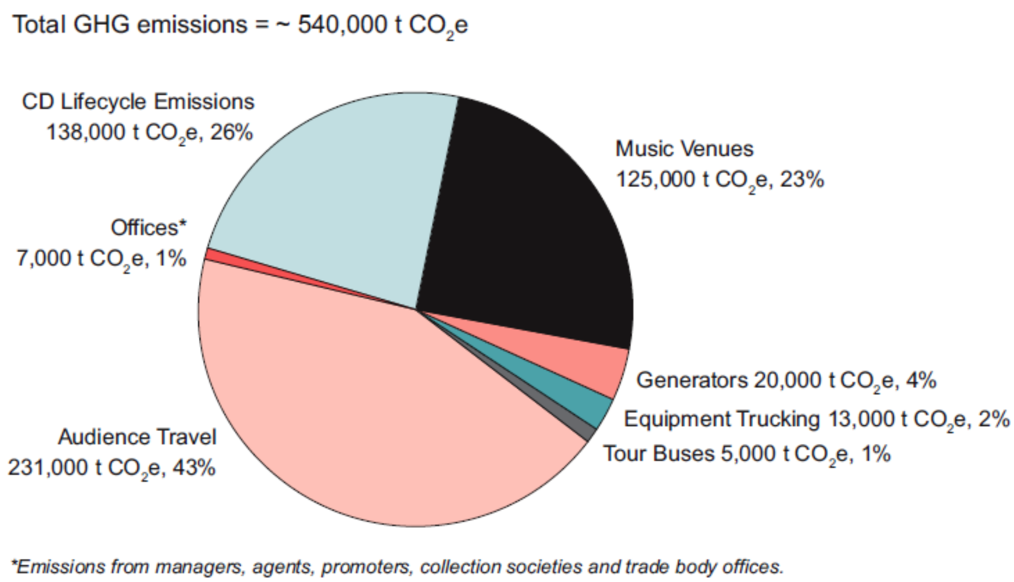

Figure 2 - Music industry GHG emissions in 2007 (Bottrill, 2008)

Of these 540,000 t CO_2e, 394,000 t CO_2e was attributed to live music performance, of which 84,000 t CO_2e was from music festivals, making festivals account for 15.6% of the music industry emissions.

The source of these emissions at a festival can be broken down in a number of ways, such as by when the emissions occur, the location they occur, who is responsible for them, or what process is responsible for the emissions. The accounting of GHG emissions presents emissions based upon the activity or process that releases them (DEFRA, 2011). At music festivals the primary processes are audience travel, on site waste disposal and on site electricity generation (Bottrill et al., 2008; Harper, 2008; Jones, 2010; Tsiarta & Heathfield, 2011). These represent three distinct fields of academic study. Audience travel is an area of study within event management, as well as wider studies of traffic management outside of events. Waste management is an area of study also found in event management, as well as linking into other subjects, such as environmental science and environmental law. On site electricity generation will primarily concern engineering and event management, however peer-reviewed literature for temporary event electrification, at the time of writing, does not exist. Such literature instead focuses on the mechanics and engineering of diesel generators under a variety of circumstances, although music festivals are not a circumstance that is examined. Event management offers work on sustainability and events in general, and represents the starting point for research in this field.

2.2 Sustainability in events management literature

In 1998, Sandra Formica quantified the topics that had been investigated under the umbrella of events research and festival research papers between 1970 and 1996, finding that the main areas of focus were economic and financial impacts, marketing, profiling of festivals and events, sponsorship, management, trends, and forecasts (Formica, 1998). However, this investigation only focussed on tourism journals, and articles may have been missed in this search if they were published elsewhere. In the time since Formica's work, subsequent literature reviews have been published looking at events related research from different perspectives. Getz (2000, 2008, 2010); Getz et al. (2010), Harris et al. (2001), Hede et al (2002, 2003), Karlsen (2005) and Sherwood (2007) all provide their own reviews on how event and festival research has changed over time. Similar topics emerged as in Formica's studies, although it is noticeable that while the themes of impact evaluation, marketing and event management were found to at least be present in all of their reviews, each found unique research gaps. The main themes uncovered in these previous reviews were typically related to the management and the financial side of festivals and events. A further review in Getz (2010) reviews the entries delivered from using the search term "festivals" in the global CIRET (Centre International de Recherches et d'Etudes Touristiques) database, and finds that the literature has a much greater focus on topics such as culture/heritage, benefits, visitors, and impacts, with topics such as management and marketing being less prevalent, suggesting that literature reviews up until that point had been narrow in their respective scopes if they had missed large quantities of cultural research. Getz suggests that the CIRET database may be "more culturally representative" due to its inclusion of non-English publications in its database. It also includes papers, books and publications from all elements of tourism, rather than the previous reviews which had focused solely upon a select series of publications, based either on geographical location or the publication theme.

What this suggests is that research into events and festivals is a diverse field, arguably more so than reviews carried out prior to Getz's review of CIRET had suggested. While this creates a wide and interesting field for researchers to work within, it does also mean that it can be a difficult field to enter into and determine what the base of knowledge is. There is however an increasing number of publications in the field in recent years, from both academic and non-academic backgrounds, as well as the formation of various bodies. These include examples such as the Association for Events Management Education (AEME), British Arts & Festivals Association (BAFA) and the Association of Independent Festivals (AIF) amongst others. It would therefore appear that the base of knowledge is improving and being developed, even if it is still unclear as to exactly what the base of knowledge is.

Until now this review has focussed upon the entire field of events literature; however this research is not for events in general, it is for the sustainability of music festivals. Sherwood (2007) suggests that the environmental impact of festivals is an area that at that point had not been explored by events academics. Since this review was published there has been a greater focus on the environmental impact of festivals, with books such as Raj & Musgrave (2009) & Jones (2010) being published, along with doctoral thesis' such as Brooks et al (2007) and Sherwood (2007) and papers such as Behr & Cierjacks (2011) and Laing & Frost (2009), with the emerging themes including sustainable event management, the processes involved in this, how to create benchmarks for these processes, and the challenges and opportunities for sustainable events. Other than these exceptions, the environmental impacts of festivals themselves however remained outside of the scope of academic journals. Much of the work contained in these publications focuses on practical guides with a "how to do it approach" (Berridge, 2007: 25). It should be emphasised though that academic and peer-reviewed literature in this field is still relatively scarce, despite the PhD research in the field during 2007 (Karlsen, 2007; Sherwood, 2007).

There is scope for a middle ground between the grey literature provided by journals, web based articles, and the more practical guides by Brooks et al (2007) and Jones (2009). This has slowly changed as the research has progressed (Lawton & Weaver, 2009; Laing & Frost, 2010; Behr & Cierjacks, 2011; Cierjacks, Behr et al., 2011), however it is still a novel topic. Certain aspects have been covered by peer reviewed research, but the majority of work in the field has occurred outside of these journals. Directly relevant literature is mostly found in independent publications, such as those by Julies Bicycle, or through web articles including blogs such A Greener Festival, newspaper articles (Edwards, 2010), official festival websites (Festival Republic, 2011) and practitioner websites (Clark, 2008).

Research in this field is often conducted independently for a specific event and not the events industry as a whole (Stentiford, 2007; Harper, 2008) although there are papers focusing on issues regarding the dissemination of knowledge to event organisers (Dickson and Arcodia, 2010), event tourism (Quinn, 2006; Bergin-Seers and Mair, 2009) and the challenges and opportunities associated with green events (Laing and Frost, 2009). It should be re-iterated however that these papers are a rarity.

In recent years organisations have begun to form in order to understand and investigate the environmental impact of festivals. These consist of organisers and practitioners, and research scholars, with the two most significant examples in the UK being Julies Bicycle and A Greener Festival. Julies Bicycle was created to analyse the GHG emissions of the music industry. They have published reports focusing on the emissions of the industry as a whole (Bottrill et al., 2008) and also specifically the audience travel patterns, and associated emissions (Bottrill et al., 2009). More recently they have provided web based tools for professionals in the music industry to estimate their carbon emissions, along with producing reports on the carbon emissions for individual events (Tsiarta& Heathfield, 2011). In comparison, A Greener Festival has acted as a body to help bring together the events industry to share best practice, and to attempt to award and categorise events based upon their sustainable practices. It has done this through use of its blog and social media, by hosting conferences and seminars, and through the use of the A Greener Festival awards, awarded as part of the UK Festival Awards (UK Festival Awards, 2011). The AGF awards are based upon the results of a 53 part questionnaire posed to the organiser, an onsite audit during the festival, and a review of the festivals literature regarding elements such as their traffic plans, waste management schemes and carbon footprint, with successful applicants for the award being categorised as 'Outstanding', 'Highly Commended', 'Commended' and 'Improving'.

In comparison to these AGF awards, Julies Bicycle has produced an 'Industry Green' mark (IG mark) which can be applied to festivals, as well as venues, offices and CD packaging. The IG mark is awarded on a scale of 1 to 3 stars based upon an audit of the organisations environmental performance, including assessment of energy, travel, waste and water associated with the subject. Unlike the AGF awards which are dealt with solely by AGF, the IG mark is verified by external assessors at the Environmental Change Institute at Oxford University and an independent Industry Green Advisory Board (Julies Bicycle, 2011).

At present, these awards and certifications are the main form of gradated environmental performance available to the public, and also act as a method of publicising both Julies Bicycle and A Greener Festival to those who may be interested. Other accreditation is available for events to publicise their efforts regarding sustainability. Industry standards such as BS 8901 (BSi, 2009) and ISO 20121 (ISO, 2010). BS 8901 was intended to be a resource that can be used so that event organisers in Britain may know what is expected of them in order to manage their event in a sustainable manner. The guidelines are aimed at the wider events industry, and as a result the guidelines are broader than simply those one may find at a festival. ISO 20121 is intended to expand on BS8901 to be an international standard after being launched to coincide with the London Olympics. The shared aim of these standards is to provide and established framework so allow event organisers to work towards sustainable development in a uniform fashion across the industry, in the same way that standards are used to ensure organisations are managed correctly in other areas of their operations.

It is important to remember that each festival will have its own unique circumstances and problems that it must consider when looking at how to reduce its green house gas (GHG) emissions. For example, island based festivals such as Bestival and the Isle of Wight festival must deal with the location of their events, and the impact that will have on travel to the event. In contrast, Download Festival is impacted by neighbouring East Midlands Airport. The proximity of an airport can reduce the carbon footprint of international festival goers, but also means that Download Festival must put extra effort in to remove the waste from the site as quickly as possible due to the potential safety implications of having extra birdlife feeding on the waste directly under the airports flight path (Probyn, 2009). The airport has also conflicted with the festival in the past regarding other issues including entertainment stalls and phone masts (Hill, 2008). While these are not environmental issues, they are useful to highlight the unique factors that each festival will encounter, and these can prove to be beneficial in improving a festivals environmental impact.

2.3 Sustainability at events – practitioners and industry examples

There are hundreds of festivals every year in Britain (Efestivals, 2012), occurring in a variety of environments which can be broken down into urban festivals (within 15 minutes walk of a train station), peri-urban (15-30 minutes' walk from a train station) and greenfield festivals (greater than 30 minutes walk from a train station) (Haworth et al, 2009). As with any kind of spectrum, each of these categories has distinct issues that it must deal with, along with distinct advantages. For example, greenfield festivals often occur on farmland or a large park where hosting a festival is not the primary purpose of the site. These sites will typically have to place a greater emphasis upon protecting the local ecosystem from the festivals impact. This is because the festival will likely be occupying an area where there is a natural environment that has little human interaction, however for one weekend a year the area will have a substantial influx of people arrive on site for the festival, along with the impact of having support staff preparing the site prior to the event and cleaning and shutting the site down once the audience has returned home. At the other end of the spectrum, urban events will have less of this impact due to the festival site usually hosting a greater amount of human traffic outside of the festival in comparison to the greenfield sites, and may be open to public access throughout the year.

Urban festivals are able to boast a number of advantages with regards to sustainability over greenfield festivals due to their location in city centres. One of the most significant benefits of being an urban festival is having access to an existing transport network that aids in allowing the public to get to and from the festival whilst reducing their carbon footprint. The issue of transport to and from a festival or event is where the majority of research in the field of sustainability at festivals lies, at least in terms of emissions directly attributable to the hosting of a festival. This research focus is understandable considering that travel emissions for festivals are easily the largest subsection of emissions, amounting to between 67% and 82% (Bottrill et al., 2008) of the average festivals emissions, excluding waste. While it can be seen how significant transport emissions are, it is important to understand how these emissions are calculated.

Method of Transport	Total GHG emissions per km
	kg CO2e per km
Average petrol car	0.25
Average diesel car	0.23
Average petrol hybrid car	0.20
Average LPG car	0.24
Average CNG car	0.22
Petrol van up to 3.5 tonne	0.29
Diesel van up to 3.5 tonne	0.30
LPG van up to 3.5 tonne	0.30
CNG van up to 3.5 tonne	0.28
Average petrol motorbike	0.14
Taxi	0.21
Average local bus	0.16
Coach	0.04
National Rail	0.07
Average domestic flight	0.21
Short-haul international flight	0.12
Long-haul international	0.14

Table 2 -DEFRA emissions for different modes of transport (kg CO_2e per person per kilometre (DEFRA, 2010)

The travel choices for festival-goers are not under the direct control of the festival organisers. A Greener Festival state that 61% of festival goers travel by car to a festival (A Greener Festival, 2011), reflecting the overall preference to travel in a car instead of public transport. Anable & Gatersleben (2005) suggest that this preference is due to the flexibility, convenience, control and freedom travelling in one's own car entails. Many major U.K. festivals are in partnership with coach companies, allowing them to provide a 'coach & festival' ticket that will bring festival attendees directly to the campsite from one of a number of locations nationwide. This is only feasible for large or major festivals however, with pickups in major cities. These packages distribute the festival entry pass whilst on board the coach, thus ensuring the coaches themselves are used to travel to the site. An undesirable result of this is that for festivals with high ticket demand, festival-goers may travel far from their place of residence in order to board the coach if they are sufficiently determined to attend the festival and a joint coach ticket is their only option.

GHG emissions derived from waste at a festival site are recognised as one of the three most significant sources of emissions. For many years the waste associated with staging a music festival has been an important issue for festivals. The phrase "leave no trace" has become popular in describing the desire to reduce on site waste (A Greener Festival, 2011). By encouraging its audience to reduce the quantity of waste deposited on site, festivals in turn will benefit from decreased time spent on site for the post-festival cleanup, decreased waste disposal costs and decreased damage to the festival site and local ecosystem.

The GHG emissions from waste do not occur on site. They instead occur as a result of the waste being processed once it has been transported from the site, either to be re-used or committed to landfill. These emissions are not under the direct control of the organisers. The organisers cannot control how much waste is deposited upon the site, and they may not be able to control the post event waste disposal process. Waste collection on site will typically be handled by volunteers and a private contractor charged with cleaning up the site post-event. Once the waste has been collected it will be removed from the site by either the private contractor charged with site cleanup, or by a separate waste disposal contractor. If a separate waste disposal contractor is used to remove the collected waste from the site, unless the organisers specifies, it would be expected that this waste would be added to the waste generated by the local borough and it will be processed in the same manner as this normal waste.

At the time of writing no data was available regarding the total amount of waste generated by the festival industry, or for the GHG emissions it incurs. Individual festival carbon footprint reports suggest it can account for between 3.8% (Glastonbury 2010) and 16.7% (Shambala 2008) of even emissions (Harper, 2008; Tsiarta& Heathfield, 2011). These figures are from Shambala Festival and Glastonbury Festival, two greenfield sites with significantly different audience figures (6700 at Shambala 2008, 140,000 at Glastonbury), and without industry wide data it is not possible to determine the significance of these figures. Other industry wide data has been collated by Julies Bicycle, however festival waste has not been collected due to the necessary data being difficult to obtain, inaccurate or not likely to be a significant emissions source (Bottrill, 2008). Given the detail necessary to create an accurate estimate for GHG emissions from waste, it is unlikely that waste was deemed to be an insignificant source.

This is a clear gap in knowledge, and there is certainly a need to quantify industry wide material consumption, waste generation, and the associated GHG emissions. Industry wide research into festival GHG emissions has been underway from the start of this research, and it was anticipated that a body such as Julies Bicycle or A Greener Festival would be better suited to collect and publish this data due to their existing industrial links, and the resolution of data they require.

2.4 Electricity use at festivals

The majority of U.K. festivals will not be able to obtain power through the national grid, and therefore make use of off grid rental power. These power companies are designed to provide electricity on a short term or emergency basis, for events such as festivals, construction or disaster relief. The primary objective for the power company is to provide continuous electricity regardless of the situation, maximising energy security. Because of this mandate, it has been suggested that diesel generators are often under-utilised and oversized, with up to 50% of the fuel going “up in smoke” (Jones, 2010).

In order to improve energy security, festival systems are typically designed to operate autonomously, with common practice using separate generators for separate areas and systems so that failure in one system will not compromise another. This can also lead to certain systems having a backup generator in addition to the primary generator (Lighting and Sound, 2010; Pearce Hire, 2010). An alternative to this is to use multiple smaller generators to power separate circuits e.g. for stages use one for variable stage lighting, one for audio and another for safety lighting. This technique is used at small events which may not be able to afford to have a spare generator that, should the event run smoothly, will not be used. The benefit of this configuration is that power can be prioritised, and while the quality of the event may be hampered by one of the generators failing, it reduces the risk of a total power failure during the weekend.

Energy security is a primary objective for festival staff during the event. Energy security ensures that the performances are unhindered and maximised with no power failures. The audiences experience is paramount, as for any festival there are a number of potential alternatives that the audience may choose to attend in subsequent years if there are believed to be problems with a festival they have attended previously.

The need for a security of supply limits the effectiveness of renewable energy technologies as a major power source for festivals. While the financial costs of RET power sources continue to decrease over time (Reuters, 2009; Gloyston, 2011; Renewable Energy World Network Editors, 2011), if a technology cannot absolutely guarantee that it can provide enough power for an event, then it can appear to be too risky for implementation. Examples such as the photovoltaic array installed on the site of Glastonbury Festival (Morris, 2010), as well as future proposed renewable installations on the site, may be capable of generating sufficient power for parts of the festival. They cannot however be guaranteed to be sufficient for the entire performance time, and as a result are due to be used to power the farm and the national grid rather than the festival (Morris, 2010; Bakewell, 2011).

At present, there are examples of companies publicising their use of biodiesel as opposed to red diesel to power their generators (Aggreko, 2009; Innovation Power, 2011; Midas, 2012). Given that festival electricity GHG emissions are calculated based upon the quantity of fuel used and the emission factor of said fuel, using biofuels with a lower emission factor than diesel should be encouraged, however reducing fuel use must also be encouraged as this will further reduce emissions. The sourcing of biodiesel also may influence its emissions factor due to the implications of purpose-grown biodiesel as opposed to recycled biodiesel such as waste vegetable oil. There are also suggestions that biodiesel can prove problematic when used in certain engines (Atadashi et al, 2010; Dwivedi et al, 2010; Fazal et al, 2011; Xue et al, 2011). For further information on biofuels, see page 35, and for further information on the scopes used in table 3, see page 29.

Fuel used	Units	**Scope 1**	**Scope 3**	**All Scopes**	**Outside of Scopes**
		kg CO2e per unit	kg CO2e per unit	kg CO2e per unit	kg CO2e per unit
Biodiesel	litres	0.02	1.35	1.37	2.49
Bioethanol	litres	0.01	0.81	0.82	1.52
Biomethane	kg	0.01	1.32	1.33	2.72
Diesel	litres	2.67	0.51	3.18	0.00
Petrol	litres	2.31	0.41	2.72	0.00
CNG	kg	2.71	0.40	3.11	0.00

Table 3 - DEFRA emissions for different fuel types (DEFRA, 2010)

The energy related emissions at a festival site are the direct result of fuel consumption on site, and the above text deals with the issue of reducing emissions resulting from energy supply, not reducing energy demand. Reducing energy demand reduces fuel demand, thereby reducing the quantity of fuel consumed. Reducing energy demand can be achieved by reducing operating hours or by reducing the demand of the equipment being used.

Reducing operating hours can only be achieved once operating hours have been established. No literature existed regarding this other than simple opening hours and artist schedules for individual festivals, so establishing existing operating hours and existing load profiles is a necessary objective for the research.

Reducing equipment demand depends on the system that is being analysed. Festival systems are generally minimalist due to being temporary systems, so in theory everything that is being used is accounted for. It is therefore unlikely that removing unnecessary equipment will result in significant reductions. Instead, low energy replacements for existing equipment should be investigated.

The primary systems under control of a festival organiser, and therefore the systems which are easier to control to reduce energy demand through equipment specification, are those relating to the stages and assorted infrastructure. Infrastructure refers to all elements of the festival, including things such as waste removal, production offices, tour buses and campsite lighting. Of these systems, each has specific requirements that cannot be easily reduced through the blanket technique of using a low energy equivalent, other than campsite lighting. Campsite lighting is a system that has the sole purpose of illumination, and therefore low energy bulbs such as compact fluorescent lamps (CFL) or light emitting diodes (LED) can be used to replace standard incandescent lamps. Campsite lighting often consists of incandescent bulbs due to there being an existing stock of these bulbs and existing lighting system designed to accommodate them. In addition, their perceived durability and lower capital costs make them easily replaceable. There have also been concerns regarding the presence of mercury in CFL bulbs (Arbuthnott, 2011; Nance et al, 2011), although it should be noted that these warnings are concerned over exposure to mercury in poorly ventilated enclosed rooms, not open air sites such as music festivals.

For stages, energy intensive equipment will be primarily due to lighting, audio and video systems. Video systems at events are typically flat LED systems, meaning video systems are already utilising low energy technology specific to that field (Adi.tv, 2012), and as a result are not an area where savings could be expected through equipment substitution. Lighting and audio systems are not as straightforward however, due in part to the number of tasks they are required to perform, and the complexity of each system.

Performance audio is provided through number of amplifiers, and these amplifiers can consist of any combination of classes A, B, AB or D. Classes A, B, and AB are all analogue and amplify the original waveform. These classes are inefficient when used at close to full capacity, and suffer heat losses as a result, which in turn can also lead to a need for mechanical ventilation and further power demand. In comparison class D, or switch-mode, amplifiers operate digitally and are able to achieve much greater power efficiencies and reduced heat losses when used to full capacity (Berglund et al, 2006; Self, 2010) when compared to analogue units in the same conditions, but may use more power at low signal levels than analogue amplifiers. The exact improvement in power efficiency varies depending upon the purpose of the amplifiers, being affected by output volume and waveform (Gaalaas, 2006; Self, 2009), and both digital and analogue amplifiers have shortcomings regarding their efficiencies at varying loads. The lack of a 'one size fits all' solution shows that while substituting technologies can theoretically improve performance, the expected savings will depend upon how the system is used.

Low energy lighting systems are in place already at certain events, such as at Roskilde Festival (Ravenhill, 2011; Roskilde Festival, 2011) or the Radiohead touring rig (Scholtus, 2008). Like campsite lighting though there are barriers to overhauling the entire system to low energy lighting due to the security and capital cost saving of utilising the existing stock, as well as the practical implications of using alternative light sources. An example of this is that LED bulbs are designed to emit 100% of their light in the hemisphere facing the target, thereby making it a more efficient method of illumination (Artemide, 2012). However, stage lighting for music performances is not designed to just illuminate the performers and audience, it is also used fill the stage with light so as to affect the "emotional response in the viewer" (Moody, 2010, P317). This light is provided by incandescent bulbs in parabolic aluminised reflector cans ('parcans'), which relies upon light being emitted into the reflectors which are behind the lamp. LED alternatives are available, however because the light fitting needs to be replaced as well as the bulb, this provides an additional incentive to rely upon the existing technology.

The use of parcan lighting rigs is an industry standard for concert lighting and has been for over 45 years (Moody, 2010, P48). With this established as the standard method for concert lighting, companies are reluctant to overhaul their entire setup in favour of a technology that would represent a large capital outlay, potential teething problems regarding its installation and operation, and a technology that staff and crew members will not be as familiar with as the existing incandescent parcan rigs. The industry standards for equipment need to be considered as well, as if a venue or festival were to invest heavily in LED lighting, then it would be risking going against the rest of the industry should the majority of other venues or festivals invest in another lighting format at a later date. This may be comparable to other 'format wars' such as the competition between the betamax and video cassette or DVD and DIVX technologies (Dranove & Grandal, 2003). It has yet to be documented whether there is any preference amongst audiences regarding particular lighting designs or lighting technologies at music concerts. Data such as this may help to lead the industry towards one technology.

From a technical standpoint, 90% reductions have been suggested for stage lighting through direct LED substitution (ETA, 2011) and given reductions of this scale, even if a fraction of the stage lighting can be replaced with low energy equivalents then savings can be expected.

2.5 Summary of knowledge gaps

It is clear the field of electricity use at festivals has not been explored by academic research, with research instead focussing upon industry wide carbon emissions, waste management and traffic management. The three primary emission categories are audience travel, on site electricity provision, and on site waste (Bottrill, 2008; Harper, 2008; Jones, 2010; Tsiarta & Heathfield, 2011). With regard to reducing these emissions, at present organisers are placing an emphasis upon managing audience transport and on site waste disposal, with electricity provision receiving less attention despite having comparable emissions to those resulting from on site waste disposal. One reason for the priority being placed upon travel and waste is because the visible congestion in surrounding roads and visible waste left behind after an event must be minimised in order to meet requirements laid out by the local council and to minimise the impact upon nearby residents (BBC News, 2007; Probyn, 2009).

At present the primary method for reducing electricity related GHG emissions is to use biodiesel instead of red diesel in generators (Aggreko, 2009; Innovation, 2011; Midas, 2012), however given that the environmental impact of bio-diesel is subject to debate, at present it should not be considered to be an all encompassing solution to reducing the environmental impact of power provision. While changing to a less emissive power source will be key to reducing emissions, this approach does not consider whether festivals are making efficient use of their electricity in the same manner that takes place in building management. This is a key knowledge gap, as without knowing how electricity is used at a festival, it is impossible to determine whether the current method of electricity provision is efficient. Given the relative cost of energy at events, the lack of research in this area was unexpected.

This thesis therefore attempts to gain a better understanding of electricity use at these events and determine standard patterns of energy demand and operation. This is a field that has no published literature about it at this time, suggesting there is a lack of existing data and knowledge in the field, and potentially a gap in knowledge for stakeholders who would benefit from increased data collection.

Chapter 3 – Carbon footprints at festivals

Introduction

Having previously established the three key areas of GHG emissions in chapter 2 (audience travel, energy and waste), this chapter will review the methodologies used to quantify emissions at festivals in order to satisfy research objective one. The chapter defines the broad terms of 'festivals' and 'sustainability' before explaining how GHG emissions are calculated in general, and in particular the individual emission sources that comprise the three emission categories; audience travel, waste and electricity provision.

The second half of the chapter presents, compares and analyses the two main GHG emission methodologies used at festivals, and discusses the merits and drawbacks of these two. An alternative methodology is also presented in the form of a case study used in conjunction with festivals monitored for the research.

Through this investigation, electricity use is found to be an area of potential research, due to its proportion of GHG emission estimates, it's clear methodological boundaries, and the potential for it to be controlled by festival organisers in comparison to waste and audience transport.

3.1 Defining carbon footprints

During the literature review for this thesis, it became apparent that the term 'carbon footprint' was open to interpretation, as well as often being used as a synonym for 'greenhouse gas emissions' (GHG), however in order to determine whether this is reasonable the two terms must first be defined. Wiedmann & Minx (2008) conducted a literary review of the term "carbon footprint" throughout the Scopus and ScienceDirect online databases in June 2007, returning 42 hits, of which none were deemed to have "an unambiguous definition" for the term, and also noted the synonymous relationship between 'carbon footprints' and 'greenhouse gas emissions'. As a result of their study, they proposed the following definition:

"The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity over the life stages of a product"

Wiedmann & Minx, 2008

As a continuation of Wiedmann & Minx's work, the researcher conducted a similar literature search, returning substantially more hits than in previous years (see table 4), however with no dedicated further discussion into the meaning of what the term means beyond Wiedmann & Minx's 2008 paper. Many pieces of work make reference to this paper, however it appears that the definition proposed by Wiedmann & Minx has not been adopted by the academic community as a whole, as 'carbon footprint' and 'greenhouse gas emissions' still appear to be interchangeable in much of the literature.

	Number of hits for "carbon footprint"		
	Wiedmann & Minx - Combined Scopus & ScienceDirect	Scopus search February 2013	ScienceDirect search February 2013
2005	3	0	7
2006	8	5	4
2007	31	87	57
2008		212	167
2009		324	374
2010		528	458
2011		789	697
2012		883	1046
2013		88	352
Total	**42**	**2916**	**3162**

Table 4- Journal database search engine hits for the term "carbon footprint" - 15/02/2013

Wiedmann & Minx's definition has been proposed in order to address the synonymy of carbon footprints and greenhouse gas emissions, the scope to which the 'carbon footprint' would address. It acknowledges that for carbon footprint accounting that certain elements may be counted multiple times, and for these purposes it would not be a suitable term, however this is not the purpose of their 'carbon footprint'. They deem the term, and concept, of a carbon footprint to be "all-encompassing and to include all possible causes that give rise to carbon emissions". From the perspective of a festival organiser, this can be a useful metric to consider the upstream and downstream emissions involved in the creation of the products used at their festival and the after-use emissions of these products. Similarly, a 'greenhouse gas footprint' would be necessary to consider the festivals entire impact regarding greenhouse gas emissions. This definition clearly states that it is only focussing upon the emissions of carbon dioxide, and no other greenhouse gases. This is useful for clarifying exactly what emissions are being considered, however this version of a carbon footprint will need to be accompanied by a series of other GHG footprints to provide the entire scope of the GHG emissions. This notion does have merit, and in terms of scientific accuracy it should be applauded, however given the widespread use of the term 'carbon footprint' as a synonym for GHG emissions it may be difficult to remove the term from the mainstream vernacular.

In the work since Wiedmann & Minx's literature review, the definition of a carbon footprint has typically focussed around defining what a carbon footprint means to a specific group or audience. Weidema et al (2008) state that carbon footprinting has "not been driven by research but rather has been promoted by nongovernmental organizations (NGOs), companies and various private initiatives", suggesting that this has resulted in a number of similar yet distinct definitions for the term. Literature since this point does attempt to move the argument on and provide a new definition to replace Wiedmann & Minx's definition, such as Wright et al (2011) proposing the following:

> "***A measure of the total amount of carbon dioxide (CO_2) and methane (CH_4) emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as carbon dioxide equivalent (CO_2e) using the relevant 100-year global warming potential (GWP100).***"
>
> Wright et al, 2011

This definition attempts to allow the synonymity of the term with GHG emissions, but to provide a set scope and boundaries for it rather than to leave it open to interpretation. The key element is that it represents multiple greenhouse gases but expresses them as a total in the units of 'carbon dioxide equivalent' (CO_2e). This allows for the additional GHG emissions to be taken into account whilst not 'sidelining' the term. The term carbon footprint has become a mainstream term and much of the general public will know to what it refers, even if the exact meaning is still open to conjecture amongst those who study the field. Interestingly, the Carbon Trust[1] in comparison moves one step further and states that:

> ***"A 'carbon footprint' measures the total greenhouse gas emissons caused directly and indirectly by a person, organisation, event or product."***
>
> Carbon Trust, 2012a

This definition suggests that carbon footprints and quantified GHG emissions are almost synonymous terms, with the GHG emissions being the physical action, and the carbon footprint is a quantitative description of this action. This definition is the one that shall be used for the thesis, as its simplicity avoids the need for debating the issue further, and clearly states that everything should be included in an object, event or processes' carbon footprint.

Carbon footprints are simply calculated by multiplying a quantity of 'activity 'for the different emission sources by its corresponding emission factor as follows:

$$GHG_{i,j} = activity_{i,j} * emission\ \ factor_{i,j}$$

Equation 1 - Calculations of greenhouse gas emissions (DEFRA, 2009, 2010, 2011)

where i is the type of greenhouse gas and j is associated with activity (e.g. distance travelled for transport GHGs). Typically emission factors for an activity will include factors for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), or a combination of these three expressed as CO_2 equivalent (CO_2e). This GHG accounting framework seeks to organise emission sources into three separate 'scopes' in order to further analyse an organisations direct and indirect emissions.

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[1]The Carbon Trust are a not-for-profit company providing specialist support to to "help buisness and the public sector cut carbon emissions" (Carbon Trust, 2012b) amongst other objectives. Much of the Trust's work regarding carbon footprinting is based upon GHG emission factors calculated by the AEA, the Department for Environment, Food and Rural Affairs (DEFRA) and the Department of Energy and Climate Change (DECC), and are published annually in documents so that organisations can report their own GHG emissions (DEFRA, 2009, 2010, 2011).

"Direct GHG emissions are emissions from sources that are owned or controlled by the reporting entity.

"Indirect GHG emissions are emissions that are a consequence of the activities of the reporting entity, but occur at sources owned or controlled by another entity.

"Scope 1: Direct GHG emissions emitted at the point of combustion of fuels.

"Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat or steam.

"Scope 3: Indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. T&D losses[2]) not covered in Scope 2, outsourced activities, waste disposal, etc."

DEFRA (2010)

The concept of using the three scopes was first suggested by the GHG protocol in 2004 (GHG Protocol, 2004) and since this time it has become a key metric for carbon accounting. This methodology is the one that shall be applied to this thesis, using the emission factors provided by DEFRA (DEFRA, 2009, 2010, 2011). This approach was chosen because it is in line with the approach of the GHG Protocol, an internationally recognised carbon accounting standard which is also used by Julies Bicycle to estimate GHG emissions across the UK music industry, as well as being used by other bodies such as the Carbon Trust, DEFRA and the GHG protocol.

3.2 Calculating greenhouse gas emissions

Using equation 1 as the basis for emission calculations, the following equations represent the application of the methodology used by the Carbon Trust, DEFRA and the GHG protocol to the three festival emission categories (travel, waste and electricity).

[2] T&D: Transmission and distribution

3.2.1 Travel emissions

$$GHG_{i,j}[kg\ CO_2e] = \sum_j dist.ance\ data_j[km\ travelled] * emission\ \ factor_i[kg\ CO_2e/km]$$

Equation 2 - Travel related green house gas emissions (generalised travel)

$$GHG_{i,j}[kg\ CO_2e] = \sum_j dist.ance\ data_j[passenger - km\ travelled] * emission\ \ factor_i[kg\ CO_2e/\ pass - km]$$

Equation 3 - Travel related green house gas emissions (individual travel)

where i is the mode of transport (own car, bus, train, taxi, etc) and j is the participant.

Audience surveys are used for determining the appropriate travel emissions. Travel surveys, such as those conducted at Shambala 2007 (Harper, 2008) ask participants about their origin, mode of travel, vehicle type and vehicle occupancy. Provided a statistically valid sample is surveyed, these results can be scaled to represent the entire audience, and provide a more reliable estimate for the total travel emissions. There are however additional journeys that are more difficult to calculate whilst keeping a survey simple enough for the public to complete. These additional journeys may be necessary to include for those travelling to the site using a coach or train, as they may have received a lift or used a taxi to travel to and from the appropriate station. The significance of these additional journeys is likely to be small in comparison to other journeys, although this cannot be quantified without the additional data.

Figure 3 - Example of festival car park

Having tens of thousands of people relocating to one site for a festival is a practicality that cannot be avoided, and it also is largely beyond the control of the organisers. Many festivals attempt to provide a shuttle bus from nearby train and bus stations, and large festivals can allocate a number of tickets specifically to coach & festival ticket packages. This however still only presents an option to the ticket holder, and cannot reduce emissions if the audience does not opt to use this option. This is therefore a systemic problem with festivals, and one that may not be able to be solved to a truly sustainable level.

For comparisons sake, it is interesting that the travel emissions are included in the footprint of a festival, as it is possible to define the boundary of a festival's impact as being the physical boundary of the site, in the same way that other confined systems do, such as the UK itself does. When considering the national carbon footprint of the UK, DECC calculate the emissions of the country itself, but do not include the emissions resulting from international aviation and shipping (DECC, 2013). The reason for including travel for an event are much more obvious though than they are for international aviation and shipping, as these forms of international travel have a number of reasons for occurring, even if the country itself was not considered, whereas travel to a festival site is carried out purely for the consumption of the event, and as such should be considered attributable to the festival.

3.2.2 Waste emissions

$$GHG_{i,j} = \sum_{j} Waste\ material_i\ [mass - kg] \times Process\ emission\ factor_j$$

Equation 4 - Calculations for waste related green house gas emissions

where i is the subset waste product under investigation, and j is the waste disposal process applied to product i.

Similarly to travel emissions, whilst the quantity of waste from the staff and production of the festival can be managed, those from the audience are much more difficult to control. A reduction in the quantity of waste is unlikely if the audience numbers stay the same, although the disposal process, both during and post event, can reduce the emission factor. Beginning with post-event disposal, if the waste can be sorted to allow for the optimal recycling or reuse method for each waste type (such as energy from waste incineration for mineral oil or closed loop recycling for plastics (DEFRA, 2009, 2010, 2011), then this ensures that the emissions factor is as low as possible. During the event however, there are a number of issues that must be tackled with on site waste disposal. First and foremost, the audience should be encouraged to deposit waste in the appropriate bins. Many festivals break this waste down into a variety of waste streams by using individual bins for each stream, such as compostable material, paper, plastic, and general waste to ease the post-event sorting process, and reduce the quantity of potentially recyclable and reusable material from generalised waste disposal (Flower, 2010).

Figure 4 - Multiple waste stream bin system

In recent years, festivals and events have employed slogans such as "Love the farm, leave no trace" (A Greener Festival, 2013) in an effort to discourage littering on site. This message now finds its focus on the campsites rather than the arena, with campaigns emerging to attempt to reduce the amount of waste left in the campsite once the audience has left. It has been suggested that a common opinion amongst audience members is that the tents that are left behind will be salvaged and reused in some manner, although festival organisers have explicitly said otherwise (A Greener Festival, 2013).

Figure 5 - Post-event campsite waste

3.2.3 Electricity emissions

$$GHG = \sum Quantity\ of\ fuel \times Fuel\ emission\ factor$$

Equation 5 - Calculations for energy related green house gas emissions

When considering how to investigate GHG emissions pertaining to electricity provision at festivals, both the activity and the emission factors specific to this process should be understood. It is currently calculated using the total diesel consumption because this is easily attainable data for an organiser, as records are kept by either themselves or their electrical power providers. The standard unit for electricity related GHG emissions in the built environment is the electricity demand, represented in kWh. In building management this data is recorded for the purposes of charging for the electricity used on the premises, but on festival sites the electricity usage is not recorded in the same fashion, as the charge will be for the fuel used and not the electricity used.

A simple total of kWh for diesel festival generators however would not be a fair reflection of the GHG emissions on site either, as the kWh per litre diesel varies with the electrical load placed upon the generator, and it is the litre of diesel that releases the greenhouse gases. The electricity consumption patterns however show the efficiency at which power is being generated, and can provide an indication as to what efficiency the generator is operating at. On a kWh/litre basis, having a generator operate as close to capacity optimises this efficiency, with efficiency decreasing considerably when operating below 50% capacity (Diesel Service & Supply, 2009; Perfect Fuel, 2009; Nayar, 2010). Appendix B contains estimates on fuel consumption rates for multiple generator sizes at difference percentage loadings.

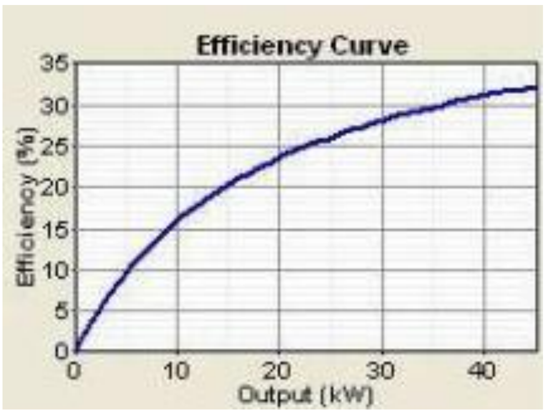


Figure 6 - Typical diesel generator fuel efficiency curve (Nayar, 2010)

The optimal solution for this problem would be to have a specific fuel efficiency curve for each generator examined, along with a record of the percentage load the generator is placed under. This will allow for each system to be analysed individually, and would provide a variable fuel consumption rate that reflects the energy use profile of the system in question. If this is not available however, approximations can be made based on the energy use profile alone, although these must be highlighted and made clear to anyone interested in the data.

Having considered the activity of fuel consumption for GHG emissions, the emission factor must also be considered. DEFRA & DECC guidelines work on the assumption that 1 litre of diesel can produce approximately 10.56 kWh of power, however multiple other sources quote generator consumption rates at between 2 and 4 kWh/litre (Katiraeri & Abbey, 2007; Weis & Ilinca, 2008; Diesel Service & Supply, 2009; Perfect Fuel, 2009). The emission factors provided by DEFRA are based upon the calorific content of diesel, listed as 45.3 GJ/tonne (MacLeay, Harris, et al, 2011), which when converted to kWh/litre, assuming a diesel density of 0.84 kg/litre (IoPST, n.d.), equates to 10.57 kWh/litre. Diesel generators however do not operate at 100% thermal efficiency, instead operating up to 32 to 36% (Bari& Esmaeil, 2009), supporting the figures provided of 2 – 4 kWh/litre.

Given that the efficiency of the diesel generators varies with load, as well as other conditions, it cannot be expected for DEFRA to provide a value other than one derived from the calorific content of the fuels themselves, although it is unfortunate that the emission factors provided by DEFRA will significantly underestimate the actual GHG emissions if applied directly to the kWh total of a power source.

Disregarding the ambiguity over the value of which emission factor should be used, another way to change the emission factor is to use a different fuel source. At present, diesel is the primary fuel source for generators at festivals, but there are attempts to move towards using biofuels with lower emission factors (Aggreko, 2009; Innovation Power, 2011; Midas, 2012). While this is well intentioned, biofuels have some drawbacks.

Biofuels as a group are a useful alternative to regular fuels due to their compatibility with existing power provision systems by either mixing biodiesel with red diesel, or using dedicated biodiesel generators. Biodiesel is a fuel constructed from vegetable oil with the intention of being used in regular diesel systems. The fuel emissions for biodiesel are 43% of those for regular diesel (DEFRA, 2009; 2010; 2011), however there is debate regarding the planting of crops specifically for the production of biodiesel around the concepts of 'food vs. fuel' and embedded energy, hence the additional emissions attributed by DEFRA for outside of the three scopes. The argument is that if crops are grown specifically to be used as fuels, they are occupying space that can be used to grow crops for food, and should biofuel crops become more profitable than food crops then food prices will inflate due to issues of supply and demand, as well as requiring energy to be grown and processed.

The least controversial biofuel is waste vegetable oil (WVO), as it consists of previously used vegetable oil, and reuses material rather than recycling it.

Figure 7 - WVO generator

Biofuels can have compatibility issues with storage containers and distribution systems, depending upon the materials it comes into contact with (National Biodiesel Board, 2012). It is therefore common to find biofuel blends are used rather than pure biofuels (AFDC, 2012) in order to improve performance and reduce compatibility issues found in pure biofuels.

For comparison, the preferred source of power would be the national grid. Having a grid connection would reduce the cost of power provision each year, and allow for the festival to reduce emissions from power provision. The grid emission factors also take account of the associated losses in electricity through transmission and distribution (DEFRA, 2009; 2010; 2011). That said, temporary power supplies are a much more viable solution for music festivals due to their flexibility, and due to the cost of connecting a remote area to the national grid for the sake of one event it is unlikely to be financially viable. Festivals also deal with long term financial uncertainty, and ordinarily do not own the land upon which the event is hosted. As a result it is understandably difficult to convince land owners, for whom part of their land value is due to the site being peaceful and unencumbered by technology, that the extension of the national grid into their lands will be of use. Another concern that the introduction of large quantities of copper to the area may lead to these sites being targeted for copper theft, much like the occurrences with unguarded railway lines (Milmo, 2011).

3.3 Parallels with GHG reduction in communities

Before examining festivals as an entity in their own right, it is worth considering some of the parallels that can be drawn between a music festival and any other congregation of people. With regards to the quantity and scale of operations required in order for a festival to function, many can be compared to villages, towns or even cities. The largest festival in the UK, Glastonbury, is listed as occupying 1,100 acres, and becomes either the 32nd or 34th largest city in the UK, depending upon which figures are used[3](Foster, 2011; Tsiarta &Heathfield, 2011; UKCities, 2012). While most festivals will not approach this scale of operations, this statistic helps to show that a festival can be considered comparable to a city, town or village. These types of communities are all accounted for through national GHG auditing conducted by DECC with documentation and work being devoted to them (DECC, 2012; Leicestershire County Council, 2005; Leicester County Council, 2010). While temporary communities such as festivals cannot be expected to be included in legislature and planning the same way as permanent communities such as towns or cities, it is worth noting this similarity in terms of scale and boundary, yet dissimilarity with respect to the legislature associated with the two types of community.

[3] Heathfield & Tsiarta list the number of tickets sold at Glastonbury as 140,000, whereas Foster lists it has a capacity of 177,000. This disparity is not referenced in either article. The researcher assumes that the "capacity" includes staff and workers, but given that this number is only needed to illustrate the scale of the festival however, this disparity is not discussed further. Any further mention of the festivals capacity assuming the figure of 140,000 due to this value being included in official documentation, Heathfield & Tsiarta (2011).

3.4 GHGs at festivals – a methodological comparison

Up until this point, grey literature regarding the methodology behind festival carbon footprinting has been lacking, with the focus has been on sustainable practices and the overall impact of a festival. None have explicitly looked at developing a carbon footprint methodology.

Methodologies have however emerged through the efforts of festivals themselves, and connected research bodies. The primary methodologies that have been used to this point are those presented by Julies Bicycle (Haworth, Tsiarta & Heathfield model) and by Shambala festival (Harper model). The Haworth model has a very clear scope and is designed to look at emissions relating to energy, waste, water and travel. Items listed as out of scope include production staff business travel, infrastructure transports, artist travel, staff commuting, off-site event management offices and the catering and merchandise supply chains. The scope of the Haworth model is constricted to solely energy, waste, water and travel, and provides a list of the quantities that are to be measured in order to determine the festivals GHG emissions.

This model builds upon previous work done by Julies Bicycle in their First Step report (Bottrill et al, 2008). First Step was intended to provide an initial estimate for greenhouse gas emissions in the UK music industry in 2007, not just music festivals. The document examines the record industry, the live music industry and the touring industry. These three areas are then broken up into 17 categories, of which one is the festival industry. This was the first attempt to determine emissions in this particular industry. The scope of First Step is important to consider, as it shows the breadth of the study and therefore the relatively shallow depth to which each element could be examined.

"This study does not provide a full carbon audit of the UK music industry. It is intended as a first and limited assessment based on estimates, case studies and data provided by a subset of the music industry. A complete assessment would require a great deal of primary research into energy use and management within individual companies and across the industry. We hope that this study will provide the basis for further analysis even as it already identifies important areas for emission reductions across the industry."

Bottrill et al (2008)

Data	Unit
Festival description	Length of event, camping or not, location (urban, peri-urban or greenfield)
Audience size	Members and days
Diesel use	Litres
Biodiesel use	Litres
Onsite renewable energy generation	kWh
Bottled gas use	kg
Mains electricity and gas use	kWh
Waste to landfill, recycling and composting	Tonnes
Water use and sewage production	Cubic metres
Audience travel – car	Average occupancy, % of audience travelling by car, average journey in miles
Audience travel – taxi	% of audience travelling by taxi, average journey in miles
Audience travel – bus/coach	% of audience travelling by bus/coach, average journey in miles
Audience travel – train	% of audience travelling by train, average journey in miles
Audience travel – ferry	% of audience travelling by ferry, average journey in miles
Audience travel – domestic flight	% of audience flying within UK, average journey in miles
Audience travel – short haul flight	% of audience flying short haul, average journey in miles
Audience travel – long haul flight	% of audience flying long haul, average journey in miles

Table 5 - Data collected for Haworth GHG model (Haworth, 2009)

Activity	Large	Medium	Small
Car	1,080	287	51
Train	382	75	6
Coach	40	15	2
Generators	210	132	18
Logistic Trucks	80	43	7
Tour Buses	38	11	2
Total	**1,830**	**563**	**86**

Table 6 - GHG emission breakdown, t CO_2e (Bottrill et al, 2008)

Bottrills breakdown of festivals is similar to the subsequent work of Julies Bicycle (Haworth, 2009; Tsiarta& Heathfield, 2011).First Step breaks festival emissions down by individual travel methods, on site diesel use, tour buses and on site logistics. This does not consider the waste or water from Tsiartas work, and is incomplete regarding its travel work in due to only providing information for cars, coaches and trains, with nothing for flights, taxis, or bikes. The distances travelled in Bottrills work are all based upon estimates too, whereas Tsiartas is based upon audience surveys. This additional detail is expected as Tsiarta& Heathfield conducted an audit of a singular festival in comparison to Bottrills initial study, of which festivals were only one part. The circumstances of each study should be considered. Bottrills was an effort to estimate the emissions of the entire industry, in a manner which had not been done previously. The research body Julies Bicycle had only recently been created in 2007, and was not an established presence at this point. Much of what is reported in First Step are estimates and extrapolations from limited data sets. In comparison, by the time of Tsiartas audit of Glastonbury Festival, Julies Bicycle was now a leading organisation in the field of sustainability in the music industry. Tsiarta & Heathfield were gathering data from one event over the course of two years, and were asking for very little data that the festival would not already have. Also by this point, there was a clearly defined checklist of data that would be required (Haworth, 2009), further simplifying the process. For the sake of comparison, the figures produced for an average large festival by Bottrill, and the emissions calculated by Tsiarta & Heathfield are presented below.

Emission source	Bottrill, 2008	Tsiarta & Heathfield, 2011	
	Average large festival 2008	Glastonbury Festival 2009	Glastonbury Festival 2010
Car	1,080	-	-
Train	382	-	-
Coach	40	-	-
Total travel	1,502	5,192	5,665
Electricity	210	-	-
Total energy use (incl gas)	-	989	1,318
Waste	-	285	179
Water	-	2	2
Logistics	80	-	-
Tour buses	38	-	-
Total	**1,830**	**6,468**	**7,264**
Audience	40,000	140,000	140,000
kg CO_2e per audience member	45.75	46.20	51.89

Table 7 - Comparison of Glastonbury to 'average' large festival (Bottrill, 2008; Tsiarta & Heathfield, 2011)

Both sets of figures have been calculated using the Julies Bicycle methodology, and as could be expected have yielded similar results. Interestingly the waste figure is found to be the least significant of electricity, travel and waste, and its inclusion in the footprint calculation does not significantly alter the kg CO_2e/person figures (44.15 for 2009 and 49.88 for 2010, both excluding waste).

As mentioned on the previous page, the Bottrill method and the associated industry averages were created as part of an initial study into the festival sector, and did not have the intention of being used as a definitive methodology for assessing greenhouse gas emissions at festivals. It is however the only existing methodology that has also been used to create industry-wide estimates. It has therefore been included in subsequent discussion and comparison, but has since been improved by Haworth for the purposes of widespread data collection and assessment, and implemented by Tsiarta & Heathfield. All of these methodologies have been published through Julies Bicycle, and as a result from this point on, the Julies Bicycle method, the Haworth method and the Tsiarta & Heathfield method should be considered synonymous with one another. The Bottrill method is not the current Julies Bicycle method, and therefore is considered separately.

The current Julies Bicycle methodological scope can be summarised as follows:

Audience travel– total of all emissions resulting from any taxis, cars, coaches, public transport and flights used by the audience in order to reach the event.

Event energy use – emissions resulting from the use of diesel, biodiesel, bottled gas, electricity and mains gas. It is not specified whether this is limited strictly to the event organisers, or whether it includes trader and contractor energy use. This can lead to confusion in reporting as the total diesel use on site is likely to include the diesel used to provide power for traders, however the supply of bottled gas at festivals is not as uniform as the supply of electricity. Standard practice for pay-to-attend music festivals is for traders to be provided with electricity by the festival rather than be required to provide their own. Free-to-attend events and festivals, such as city based events, can instead instruct traders to provide their own power as a mobile generator network may not be feasible, or necessary, for these events. In the Glastonbury case studies of 2009 and 2010 (Tsiarta& Heathfield, 2011) 159,300 litres and 174,200 litres (respectively) of bottled gas are listed as being used during the festival. This much gas is likely to include gas used by traders, however it is not clear whether this is the case. The embodied energy of acquiring the system (the festivals portion of the production emissions of the generators, cabling, etc) and the emissions resulting from the transportation of the system are not included.

Event waste – emissions resulting from waste that is generated on the festival site. In order to calculate this there must be a breakdown of the individual elements that are collected, and how they are processed once they have been removed from the site (e.g. landfill, recycling, composting).

Event water use and sewerage – Emissions resulting from the UK average emissions from water treatment and sewage treatment. The embodied energy of acquiring and installing the system (the festivals portion of the production emissions of the piping, pumps, etc) and the emissions resulting in the transportation of the system are not included.

Areas not included in the scope – Production staff travel, infrastructure transport, artist travel, staff commuting, off-site event management offices, catering supply chain and merchandise supply chain. These are however acknowledged to be significant secondary emissions and should be addressed to reduce environmental impacts. (Haworth, 2009).

In comparison, the work carried out at Shambala festival by Peter Harper instead has a much more theoretical approach. His work conceptualises the processes involved in the 'event' of a music festival. The Harper model is framed initially as a series of bullet point questions, before being turned into the reporting table, table 8.

1. What categories of emissions can be measured?
    a. Travel
    b. Operational energy
    c. Goods, materials and services
    d. Waste
2. Who is emitting them?
    a. The organisers
    b. The venue
    c. The participants
    d. Subcontractors
3. When?
    a. Before the event
    b. During the event
    c. After the event

Subsequently this methodology was altered to consider the 'core footprint' and the 'peripheral footprint', where the core emissions are those generated by the festival, on behalf of the festival in providing the event, and the peripheral emissions are generated by the festival's audience consuming the event (Harper, 2010). At Shambala 2010, it was estimated that the core footprint was responsible for 25% of the festival's emissions, whilst the peripheral footprint was responsible for 75%. The scope of the Harper methodology is shown below, and wherever possible, each of the four categories of emission are apportioned to the responsible party out of organisers/venue, third party subcontractors or traders, and participants who are also referred to as the "peripheral carbon footprint". This is then displayed in the grid form seen in table 8.

Travel – Refers to emissions resulting from any travel taking place as a result of the festival. All emissions caused in the process of transporting the audience to the festival are attributed to participant travel emissions. All emissions caused in the process of transporting third party subcontractors are attributed to their travel emissions. Organiser and venue transport is determined by pre-festival travel by organisers, as well as including the emissions of the festival crew as apportioned by their 'participation factor' (see table 11).

Event energy use – emissions resulting from the use of electricity, bottled gas, office functions in preparation for the festival, and energy use of the participants. Organiser and venue energy is determined by energy use in office functions to prepare for the festival, as well as the energy use on site from power generators and bottled gas. Third party subcontractor energy emissions are calculated solely based on their bottled gas use. Participant energy use is determined by the energy use of the participants whilst on site. Harper (2010) works solely from an estimate for this value.

Waste – Comprised of emissions resulting from the transportation of liquid waste and sewage from the site, the festivals portion in the embodied energy in the production of the onsite toilets, and the emissions resulting from solid waste generated on the site. Harper (2008; 2010) poses the question that how much of this waste should be attributed to the festival given that the audience would still require food, and produce waste whether they attended the festival or not. The proposed solution is to estimate the emissions the audience would have generated should they not attend the event, and attribute this to the participants. Any remainder from this should be attributed to the organisers and venue.

Embodied in goods and services – emissions emitted in the production of goods and materials used at the festival. These goods are split between "durable goods" which are re-used, and "consumables" that are either consumed, or become waste (Harper, 2010). Consumables that would be used the same if participants did not attend the festival are ignored. The consumables that are assumed to be used more during the festival are beer, wine, spirits, soft drinks and gas. It is assumed that these products will be consumed twice as much as if they had not attended. Emissions from durable goods such as stage equipment and tents are described as a weak part of the carbon footprint analysis due to the number of assumptions made (Harper, 2010). All embodied emissions from durables such as festival stages and equipment are attributed to the organisers. All consumables are subject to the participation factor split (attributed to participants and organisers), and third party contractors are estimated as being 10 times that of a participant (Harper 2008; 2010).

Areas not included in the scope – The only issues not directly addressed in the Harper model are those relating to the supply chain where data would not be feasible.

	Categories of emissions generation				
Functional parties	Travel	Operational energy	Embodied in goods and services	Waste	Totals
Organisers / Venue					
Third party subcontractors					
Core totals					
Participants (Peripheral carbon footprint)					
Extended totals					

Table 8 - Breakdown of emissions categories (Harper, 2010)

This is a more detailed framework and allows for much greater analysis in comparison to the models provided by Julies Bicycle. The Harper method is able to attribute emissions to each emission category and each functional party, as well as provide the emission totals that the JB method provides. Harper also breaks the emissions down into the core and peripheral emissions. Core emissions are attributed to the festival organisers, the venue, the subcontractors, and essentially everything that doesn't purchase a ticket to get into the festival, or rather the core emissions are the emissions the festival would be responsible for should there be zero attendance, assuming the event still occurs.

The problem with the Harper method rather than the Julies Bicycle method however is that the additional details in turn it requires additional data. Harper acknowledges that many of his figures are based upon "guesstimates", arguing that it is "better to make an informed guess than to ignore a factor altogether" (Harper, 2008). In line with this, Harper (2010) goes on to describe the updated approach as a "sophisticated back-of-envelope" method of calculation, using "general principles and making informed estimates, to arrive at a provisional answer that is probably within 10% of the 'real' answer".

The information that the Harper method attempts to provide is commendable, however much of it is based upon estimation and supposition (although all estimation is clearly highlighted), with only the organiser energy, audience travel, and overall waste using recorded data. In terms of calculated emissions, the Harper method details the same quantities as the Haworth method, and does so with a deeper and more transparent methodology, however the end result for a single footprint is comparable.

Having considered the difference in approach of these methodologies, it would be worthwhile comparing the figures that each technique produces. Given that many of the statistics provided in Harper's work are based upon estimates, the models are compared on the basis of their results for audience travel, electricity provision and waste, the three primary emission categories.

			Emissions (tonnes CO2e, percentage of total emissions)						
Model used	Festival	Approximate audience size	Audience travel		Electricity provision		Waste		Total
Harper 2008	Shambala 2007	6700	240	64.0%	25	6.7%	63	16.7%	375
	Shambala 2008	9000	361	76.3%	5	1.0%	49	10.3%	473
Harper 2010	Shambala 2010	9691	272	69.0%	11	2.8%	111	28.3%	394
Bottrill 2008	Generic small 2007	<10,000	59	68.6%	18	20.9%	-	-	86
	Generic medium 2007	10,000-40,000	377	67.0%	132	23.4%	-	-	563
	Generic large 2007	>40,000	1502	82.1%	210	11.5%	-	-	1830
Tsiarta & Heathfield 2011	Glastonbury 2009	140,000	5192	80.3%	989	15.3%	285	4.4%	6468
	Glastonbury 2010	140,000	5665	78.0%	1318	18.1%	279	3.8%	7264

Table 9 - Comparison of emissions between different models (Harper, 2008, 2010; Bottrill, 2008; Tsiarta & Heathfield, 2011)

The total emissions under the Harper methodologies are all larger than would be expected under the Bottrill method, even when the waste element is discounted. This is due to the audience travel emissions being much closer to those for a generic medium festival than a generic small festival, although it is worth highlighting that a small festival in the Bottrill method will include a number of community festivals. These festivals can be expected to have less travel emissions due to their focus on the local community, rather than a festival that advertises nationwide.

The additional emissions from transport in the Harper method, in comparison to the Bottrill method, are due to a difference in estimated audience journey distances, and type of journey breakdown (see table 10). Both Harper methodologies assume a much larger distance travelled than the Bottrill methodology.

	Average car return distance	Average train return distance	Average coach return distance	Travel mode split
Bottrill 2008	50% of audience – 100 miles, 50% 50 miles	50% of audience – 100 miles, 50% 50 miles	100 miles	Car 70%, Train 15%, Coach 15%
Harper 2008	426 km	456 km	268 km	Car & van 77%, Train 14% Coach 7% Other 1%
Harper 2010	150 km	150 km	Not specified	Car not specified, Train 12% Coach not specified, Other not specified

Table 10 - Assumed or average recorded distance travelled for each methodology (Bottrill, 2008; Harper, 2008, 2010)

The difference in the average distance for each case should mean that each case has significantly different travel emissions, however this is not the case. Emissions are similar for both Shambala 2007 and 2010, despite large changes in the average distance travelled. The Shambala 2007 figure of 240 tonnes CO_2e is listed as an estimate between two values; approximately 180 tCO_2e and approximately 272 tCO_2e. The 180 tonne estimate is based on an audience travel survey (3.5 people per car), whereas the 272 tonne estimate is based on counting parked vehicles (1.79 people per car). The 240 tCO_2e estimate is adopted as "a kind of weighted average" between the two, and Harper suggests that the audience survey may have been weighted due to it being conducted in mostly in the family area, also postulating that this may have increased the average distance travelled. In comparison, the Bottrill travel distances suffer from being estimates that are created to describe all types of small festivals, which as previously mentioned will include local festivals that are not comparable to Shambala festival in anything other than the number of attendees.

In 2008 there was no repeat of the 2007 travel survey, although there was a repeat of the vehicle survey in the car parks. This data is extrapolated in conjunction with the 2007 travel survey to estimate the emissions of the audience in 2008. Harper theorises that the emissions increase to 40 kgCO_2e pp from 35.8 kgCO_2e pp was the result of the 2007 estimate being too low.

Overall, the reliability of these data is cause for concern when comparing the festivals emissions with other similar events. The data from these two years has been questioned in Harper (2010), where it is described as “hastily collected” (Harper, 2010). However given the paucity of data available in this field, it needs to be included in analysis. The difference in calculation methods, and the difference in emission totals from year to year suggest that there is a need for a clearly defined, and continuously executed methodology that is used year on year in order to avoid confusion.

Shambalas 2010 audience travel estimates are not published as part of the festivals GHG analysis (Harper, 2010), instead referring to a “registration and tracking system” used to calculate the distance travelled through using the post-code of ticket holders. The data-set containing these details is described as “reliable and fairly accurate”, however it is not included in the report.

One element of these footprints that has been alluded to but not directly addressed is how to make these footprints comparable between events of different sizes. The standard practice for this is to use either the site capacity, or the number of ‘audience days’ at an event. Audience days represent the number of people on site multiplied by the number of days, so a 10,000 person festival for 3 days would represent 30,000 audience days. The capacity is a useful figure to use when comparing the data of events that take place over a similar amount of time, or data that is not dependent upon the duration of the event, such as audience travel to and from the event. Audience days are more useful when comparing data that has an element of time dependency as well as being a function of audience size, such as total waste generated on site. Harper proposes the use of an ‘equivalent participant day’ (Harper, 2010). The difference between this and the audience day is the definition of an audience member and an equivalent participant. There is ambiguity over whether a festival should be measured by its audience or capacity (see footnote on page36) and the equivalent participant is an attempt to clarify this. This model works on the principle that everyone on the festival site will be a participant in the event, but each to a varying degree. In the 2010 analysis of Shambala, Harper assumes the following ratios for each group of people on site:

Group	Participation ratio
Participant	100%
Base crew and traders	20%
Main crew and artists	50%

Table 11- Participation ratios for equivalent participant days (Harper, 2010)

These values are admitted to be an "arbitrary assumption", but are an interesting technique to account for how much each of these groups can be said to be attributable as participants at the festival, as well as attributed to working at the event. These ratios would be applied to the number of people in each grouping to attain a total 'equivalent audience'. In this instance, the number of ticket holders at Shambala was listed as 9,691, the number of equivalent participants was 11,855 and the number of people admitted to the site over the festival was 14,151. The equivalent participant number is an interesting figure for providing "fuzzy accuracy" rather than "false precision" (Harper, 2010), but it is based on assumptions that are of little use for standardisation beyond a singular event.

In summary, both methodologies are possibly best considered when they are put into context with what their purposes are. The Harper methodology is designed to be incorporate as much of the festivals environmental impact as possible and be provided to a singular client. The methodology provides a conceptual guide to how the festival fits together, and sacrifices reporting accuracy for the sake of providing an all encompassing figure that includes elements that have been estimated and assumed. These estimates are highlighted in order to clarify what has been directly calculated and what has been estimated, and the method as a whole can be seen as evolving through successive years. The method is entirely transparent, and each element is debated so that the reader can understand both the final result, but also the issues associated with that result. In comparison, the Julies Bicycle methodology is clear and concise, and is built upon a few key pieces of data. This methodology has been created with the intention of creating a simple tool that event organisers can use to calculate their own emissions with minimal effort, using data they should have access to without the incentive of determining their emissions. It is a much more formal presentation of the data, and as a result it loses some of the "fuzzy accuracy" of the Harper method. Both methodologies are useful, as both provide a clear picture of a festival's emissions and how these emissions break down, however what one gains in ease of completion, the other gains in its extended scope.

3.5 De Montfort Hall festival emissions

Festivals at De Montfort Hall were used as a case study to quantify emissions at festivals studied in the research. These emissions were calculated using the equations in section3.2, using data provided by festival organisers, Leicester Energy Agency, and audience travel surveys. Emission factors were provided by the relevant copies of DEFRA guidelines (DEFRA, 2009; 2010; 2011). The only data not ordinarily collected by the festival organiser in this instance were the audience travel surveys, although organisers typically have at least a low resolution dataset similar to this to suggest general audience demographics. These surveys were completed by audience members on site. Surveys were located in the Face Your Elephant exhibit, and in the entrance to De Montfort Hall foyer. Audience members were incentivised with the offer of a pair of free tickets to the festival in the subsequent year.

The methodology used for these calculations is an extension to the methodology used by Julies Bicycle. The footprints were created using data available to the festival organisers in order to demonstrate the additional detail that can be achieved without any additional data collection, other than using estimates for emissions resulting from power consumption for individual stages, based on data recorded for further analysis within the thesis. The methodology used for data collection in these systems can be found in chapter 4. All values are calculated using DEFRA emission factors, however emissions from individual systems powered by diesel generators were calculated using the emission factor for volume of diesel and an average fuel consumption rate of 3.1 kWh per litre, based on Diesel Service & Supply (2009) and Perfect Fuel (2009).

These breakdowns were presented to the festival's organisers after the event, and were subsequently included for A Greener Festival awards in each instance.

When compared to the figures provided by Harper and Bottrill for other small festivals, both Big Session and Summer Sundae recorded similar figures. The similarity in emissions from travel between BSF and SSW, despite SSW having approximately 4 times the audience, is due to a greater proportion of the audience travelling to BSF in private vehicles, whereas SSW demonstrates substantial uptake in public transport. Waste emissions are greatly reduced at these events due to their urban location. Being an urban festival, many systems already exist in order to deal with waste on site, such as toilets and bins, and the proximity to the city means that some of the waste generated by the festival will be dealt with off-site. The ability to commute to the event rather than camp for the weekend will also remove a portion of the waste to the audience's homes as well.

Electricity provision emissions are greatly reduced at BSF when compared to Harper and Bottrills estimates. This is due to the size of the event, and the utilisation of the national grid. This substitution reduces emissions by 47%[4] in comparison to standard diesel generators. The values presented for subsystems do not represent the entire site, hence their total not equalling the site total. Electricity provision emissions at SSW are in line with early Harper and Bottrill estimates from, however subsequent Harper estimates appearing reduced due to the use of biodiesel.

Overall, the figures show both festivals to not be performing significantly differently to others within the industry considering the environment and utilities available to them. The additional presented detail to break down emissions beyond the headings of 'waste', 'travel' and 'electricity' allows the emissions figures to provide more information than a total value, such as with difference in transport options chosen by those attending BSF and those attending SSW. This data is a product of a travel survey already conducted for the festival, however through presenting the emissions in this manner, GHG emission reductions can be quantified in a more relevant manner, such as being able to view the reduction in emissions from people moving from car shares to trains between 2010 and 2011 at SSW.

[4] 0.55 kg CO_2e/kWh for UK national grid electricity (DEFRA 2012), all scopes compared to 1.03 kg CO_2e/kWh for diesel generators assuming 3.18 kg CO_2e/litre (DEFRA 2009; 2010; 2011) and a fuel efficiency of 3.1 kWh/litre (Diesel Service & Supply, 2009; Perfect Fuel, 2009)

	BSF 09	BSF 10		SSW 09	SSW 10	SSW 11
Emission Source	tonnes CO2e	tonnes CO2e	**Emission Source**	tonnes CO2e	tonnes CO2e	tonnes CO2e
Travel			**Travel**			
Own Vehicles			Own Vehicles			
Single occupancy cars	22.8	6.1	Single occupancy cars	13.6	5.7	8.7
Car shares or multiple occupancy	11.6	22.5	Car shares or multiple occupancy	26.5	38.7	20.6
Motorcycles	0.0	0.0	Motorcycles	0.0	0.2	0.0
Live-in vehicles	3.3	3.3	Live-in vehicles	1.5	1.8	3.2
Public Transport			Public Transport			
Local buses	0.1	0.1	Local buses	0.4	0.2	1.8
Coaches	0.1	0.0	Coaches	0.1	0.3	0.3
Taxi	0.0	0.0	Taxi	0.4	0.4	0.9
Train	1.4	2.2	Train	3.2	3.9	6.4
Plane	8.8	8.0	Plane	2.0	2.2	0.0
Total	48.1	42.4	**Total**	47.8	53.5	41.9
Logistics Trucks	1.6	2.0	**Logistics Trucks**	2.6	3.2	5.2
Waste			**Waste**			
Recycling	0.5	-	Recycling	3.0	-4.2	-4.3
Landfill	0.6	-	Landfill	3.0	2.4	0.0
Virgin production	8.5	-	Virgin production	45.5	21.6	27.6
			Energy from waste	0.0	0.0	-0.4
			Composting	0.0	0.0	0.0
Total	9.6	0.0	**Total**	51.6	19.8	23.0
Water			**Water**			
Water consumption	0.1	0.0	Water consumption	0.1	0.1	0.1
Wastewater	0.1	0.1	Wastewater	0.2	0.1	0.1
Total	0.2	0.1	**Total**	0.3	0.2	0.1
Electricity			**Electricity**			
Grid Electricity	4.7	6.4	Grid Electricity	5.9	7.7	6.7
Big Top Stage	-	0.5	Musician bar & stage	-	0.7	0.6
Orange Tree bar & stage	-	0.5	Mainstage lighting	-	0.8	-
Traders		0.9				
			Diesel Generators	-	12.6	17.5
			Rising stage	-	1.5	1.7
			Traders	-	-	1.9
Total	4.7	8.5	**Total**	5.9	20.2	24.2
Total	64.1	53.0	**Total**	108.3	96.9	94.4

Table 12 - Greenhouse gas emissions at Big Session Festival and Summer Sundae Weekender

3.6 Summary

This chapter has reiterated the primary areas of GHG emission at festivals, and subsequently compared the methodologies for which these emissions are calculated and conceptualised. The two primary methodologies for this process have been compared, with one providing a more detailed theoretical approach, and the other providing a much easier to use methodology that can be used for widespread data collection. Both methodologies add value to the field and have been found to provide comparable results, with the primary difference being the ease of data collection for the Julies Bicycle methodology. For standardisation purposes, the simplicity of the Julies Bicycle model allows for easy comparisons between festivals with existing data, however this methodology can be extended to include additional data whilst still producing comparable results, as shown using the De Montfort Hall festivals as a case study. The Harper model takes this much further, but is subsequently a less precise model due to more estimation.

Both methodologies however do not address the aspect of energy efficiency within power provision at festivals, and use only the total fuel use of a festival to calculate the associated GHG emissions. This is understandable, given that the fuel is the source of the emissions, and is readily available data. However by only collecting one piece of data, this does not allow for any deeper analysis that can identify opportunities for change, other than reducing the festivals fuel consumption.

This lack of consideration to energy use beyond a singular total of fuel consumption provides justification for the energy analysis conducted in this thesis. Trends in energy use can identify areas of inefficiency in the power provision system, which can in turn be addressed in order to reduce GHG emissions though either a reduction in the emission factor for power provision, or a reduction in power demand and fuel consumption. Chapter 4 will now discuss the practical methodology for this research in order to satisfy research objectives two and three, and how it will be geared to fitting into a real world environment that can present challenges towards data collection.

Chapter 4 – Research and data acquisition methodology

Introduction

The purpose of chapter 4 is to describe the methodology and data acquisition process from a theoretical perspective of what is measured and why, as well as from a practical perspective regarding the physical process involved with data collection.

In the three previous chapters, the current state of sustainability in the festival sector has been outlined, and the three primary categories of emissions have been identified. The purpose of chapter 4 is to explain the methodology used to investigate electricity consumption at festivals, in both theoretical and practical terms. As well as detailing the data acquisition process, the chapter also addresses the research approach for the thesis as a whole, outlining the systems that are monitored, why they have been chosen, and how this adds value to the research.

4.1 Undertaking power monitoring at music festivals

Any device designed to record power consumption through electrical measurement will record two quantities for a particular circuit; the circuit's current (amps) and the circuit's voltage (volts). These will be the quantities that are measured in order to determine the power consumption for each reading due to the combination of Joule's and Ohm's laws.

$$P = I \times V$$

Equation 6 - Electrical power as dictated through Joule's and Ohm's laws.

where P is electrical power (VA), I is electrical current (amps) and V is voltage (volts).

The environment of a music festival makes the collection of power data collection through traditional power monitors problematic. Any datalogger that records voltage must be physically connected into the circuit is therefore considered to be invasive, and usually requires the power to be disconnected, or deactivated whilst the datalogger is installed. This is undesirable at a music festival at any point due to the loss of an uninterrupted power supply. An alternative would be to install the datalogger prior to the power being activated and removed once the demand for power had finished. In some systems, the generator may be active from the moment the site crew arrive on site, and can potentially run until they are ready to leave. While this provides additional data for each event, it limits the number of events that can be monitored.

Electrical current however can be recorded non-invasively using current transformers. Current transformers can be attached around the cabling of a circuit and can record the current draw using the magnetic field generated by the wire. This process works on the assumption that the voltage is constant, and has the advantage of being non-invasive. It therefore does not influence the circuit in any way, remaining an impartial observer, as well as not presenting a threat to the systems energy security or quality of power supply. It is important to remember that the primary responsibility of the power provider is to ensure that over the course of the festival, power is provided to those who have paid for it, and therefore anything that may reduce the likelihood of achieving this goal is a potential threat.

The majority of generators used on site will use three-phase supplies consisting of power split between three separate cables in order to transmit the same level of power with greater efficiency and lower safety risk.

In a practical sense, a three phase circuit will comprise of five cables: phase 1, phase 2, phase 3, ground or earth, and neutral. In order to record the current load on a three phase system, it requires three times the amount of current transformers to monitor three phases as opposed to one. The neutral or ground wire can also be monitored as well, but this is not essential for calculating total demand. When applied to an unbalanced three phase power supply, which all the systems monitored were found to be, equation 6is adapted as follows;

$$P = V_a I_a + V_b I_b + V_c I_c$$

Equation 7 - Instantaneous apparent power in a linear, unbalanced three phase power supply (Sabater & Donderis, 2004)

where subscripts a, b and c are used to represent the voltage and current in each individual phase. If the line to neutral voltage is assumed to be equal, across all three phases, this becomes;

$$P = V \times (I_a + I_b + I_c)$$

Equation 8 - Instantaneous apparent power in a linear, unbalanced three phase power supply, assuming constant and equal voltage.

Voltage was assumed to be 230 volts, the UK nominal voltage (BSi British Standards, 2011). This value was supported by on-site inspection, with an error of 5% (see figure 13).

This provides the apparent power of a system in volt-amps (VA), which is then multiplied by the power factor of the system to provide the real power in watts (W), thereby allowing for kWh comparisons with other systems. Power factor is assumed to be 0.8 (see page 90 for more details on power factor).

In order to record current demand across all three phases, current transformers must be attached to each individual phase. These transformers will record the current passing through their respective cables, sending a signal to the datalogger. The logger will be recording this every minute in order to provide a high resolution plot of current demand over the course of the weekend, which can then be analysed through the analysis techniques described in chapter 5. These loggers must be installed on each individual phase, and will need to be located near the power source before the overall load is distributed to smaller, immeasurable systems. This means that for most systems the loggers will be installed upon the primary cables emerging from the generator itself. Sufficiently large systems (e.g. large main stages) may have subsequent split cable systems after the first distribution point. If so, these can be monitored as well to provide a further breakdown of data.

The use of split cable distribution (often referred to as ‘powerlock cabling’ due to brand synonymy, such as with vacuum cleaners and the Hoover brand) is not commonly found in smaller generators (e.g. those smaller than 100 kVA). As a result, this data collection technique is likely to only be of use for the largest generators and distribution networks at the festival site. The advantage to this is that it can allow for easy characterisation of the most demanding systems, and is therefore working with systems that are responsible for greater emissions. However, the data is at a disadvantage due to the lack of information on smaller systems, which are more likely to be replaceable with renewable power supplies such as photovoltaics with battery backup.

Figure 8 - Current clamps around cables L3, L2, L1 and neutral (left to right)

The installation and removal of this equipment was carried out using the following procedure:

1. Ensure area is safe for work.
2. If so, determine if generator is operating with powerlock, 5-cable set up. If so, proceed to task 7. If not, proceed to task 3.
3. Determine if power cable has a split tail[5] within the generator casing.
4. If split tail is present, determine if split tails are safe to work with.
5. If not, do not continue with monitoring.
6. Identify all 5 cables.
7. Attach current transformer in position 1 on the datalogger to phase 1.
8. Attach current transformer in position 2 on the datalogger to phase 2.
9. Attach current transformer in position 3 on the datalogger to phase 3.
10. Attach current transformer in position 4 on the datalogger to the neutral.
11. Ensure datalogger and current transformers are safe from potential interference, weather conditions, and will not disrupt festival operations.
12. Leave datalogger and current transformers.
13. After festival, return to collect datalogger and current transformers.
14. Check to determine if all equipment is still present and in working order.
15. Ensure area is safe for work.
16. If so, uninstall equipment.

[5] A split tail cable refers to a cable that contains all of the individual phases within the casing, but separates into five separate connectors within the generator. These connectors will correspond with each of the three phases, earth, and neutral.

This process refers to monitoring the current flow directly from the generator. All systems will have a distribution box connected to the generator to allow for separate systems to connect into the power supply. Some of the associated subsystems may also use three phase power through powerlocks, allowing for further submetering. An example of this is the use of distribution boxes for main stages which divide the lighting, audio and video systems into separate power feeds (see figure below).

Figure 9 - Main stage distribution boxes for separate stage systems such as lighting, audio and video

There is more depth to the electronics of temporary, three-phase power than has been discussed in this section, including issues relating to the power quality, the harmonics and balance of the three phases, and the inductive and capacitive loads placed upon each generator. These issues are not be addressed in this study, as this research is focusing on identifying energy profiles, trends in energy use, and the potential scale of any existing inefficiencies. These practical issues are all inefficiencies that will be factored into the power requirements for a site by the power provider and should be considered in any work following on from this research, as well as being the subject for further research themselves.

This is the depth to which this thesis will deal with these issues, as due to logistical reasons the data gathered only allows for analysis of the three phase current supply. While these issues are influencing factors, it is not within the scope of this thesis to discuss them in any meaningful sense without further data. They should all be topics of future research however, as they are gaps in knowledge that, if investigated, may identify other opportunities to improve energy efficiency at festivals and other temporary events.

4.1.1 Monitoring equipment

Four different types of data acquisition equipment were used for the study; Dent Datapro, Dent ElitePro, Elcomponent SPCMini and Hobo U12 loggers. These were selected due to their ease of use and applicability for monitoring electrical current, as well as drawing upon existing expertise with this equipment within the IESD. Little difference was found between each type of datalogger. The Hobo dataloggers were notably smaller and lighter than their Dent and Elcomponent counterparts, making transport and installation quicker and easier with these units. Data extraction was carried out using the proprietary software for each datalogger; Elog for Dent units, PowerPackPro for Elcomponent units and HOBOware Pro for Hobo units. Microsoft Excel was used to store all of the raw data, as well as for data processing and analysis due to the ease at which data could be handled and distributed to festival stakeholders when required. All dataloggers recorded current data as root mean square (RMS) values, rather than instantaneous values.

4.2 Electricity use at festivals

The main electricity uses at festivals can be broken down to three categories; stages and performance areas, traders and contractors, and site infrastructure.

Performance areas refer to the stages used by the artists on site. The size and scale of these areas varies significantly from festival to festival, but the main music stages at each event were the most intensive singular energy systems on the site, particularly at larger events. The typical power layout will have a separate power source for each stage, and this power source will be used exclusively by the stage and any nearby associated systems, such as artist hospitality.

Figure 10 - Example of main stage performance area

The term 'traders' refers to every stall on site which engages with the public that is not controlled by the festival. The majority of these traders will operate out of one stall at the event for the purpose of selling goods or services to the public, such as clothing stalls or food stalls. Festival bars are classed as traders under these descriptions. At small festivals there may be a number of contractors collaborating to provide the bars, however at medium sized festivals upwards, bars are typically provided by a sole contractor. The site layout will be arranged so that the traders are grouped together into 'islands' in order to provide an area behind the traders for storage, parking, preparation and camping. Each trader island is then provided with an independent power source, thereby reducing the quantity of cabling and complication involved in power provision. Depending upon their location, the power supply for the bars may be the same as for nearby traders or stages, or they be provided with their own independent power source. The number of trader islands varies depending upon the size and layout of a festival, with small and medium festivals rarely using more than 3. Large and major festivals however can be expected to have significantly more due to the size of the event.

Figure 11 - Example of trader stalls

Site infrastructure refers to the infrastructure that is required for the festival to operate safely and correctly. It refers to systems such as campsite lighting, production spaces, waste facilities, catering, and tour bus power provision.

Figure 12 - Example of small campsite lighting generator

The plan for this research was to acquire sufficient data to understand electricity use in each of the systems listed above, with the intention of discovering how much power each was using over the course of a festival, and relating that back to their associated GHG emissions.

> Year one – gather preliminary data. This was a pilot year where the data acquisition system was tested, and the researcher engaged heavily with organisers and power providers.
>
> Year two – Measure preliminary data again in order to extend the dataset. Expand to additional systems where possible at these festivals, as well as employing the same techniques at festivals not covered in year one.
>
> Year three – Focus on other datasets not covered in the first two years. Year one and year two focus on examining stages, with year three focusing on traders and infrastructure systems. Where possible, systems that did not have two years worth of data in year two are measured too.
>
> Year four – Following engagement with festival organisers and power providers, demand for further monitoring had been established. This industry engagement led to data being used in the Power Behind Festivals report (Johnson, Marchini et al, 2012). As a result, it was decided that additional data collection in year four would be of benefit to the industry, the research institute, and the researcher. At festivals that had previously been examined, the focus in year four was to continue data collection from previous years to create long term datasets. At festivals that had not previously been examined, the opportunity arose to measure additional aspects of the infrastructure, namely the campsite lighting and production compound power demand as individual systems. Previously these had been combined in year three datasets.

Table 13 describes the systems monitored, and can be found in appendix C as well.

Year	Festival	Festival size (Haworth)	System category	System type	System description	System key
2009	A	Small	Total festival	Total festival	Total Festival	A1
	B	Large	Stage	Lighting	Main Stage Lighting	B1
			Stage	Audio	Main Stage Audio	B2
			Stage	Video	Main Stage Video	B3
	C	Medium	Total festival	Total festival	Total Festival	C1
	D	Major	Stage	Lighting	Main Stage Lighting 1	D1
			Stage	Lighting	Main Stage Lighting 2	D2
			Stage	Lighting	Main Stage Lighting - Total	∑ D1-D2
			Stage	Audio/Video	Main Stage Audio + Video	D3
2010	E	Small	Total festival	Total festival	Total Festival	E1
			Traders	Traders	Total Traders	E2
			Stage	Lighting	Second Stage Lighting	E3
			Stage	Lighting	Second Stage Emergency Lighting	E4
			Traders/stage	Bar/total stage	Bar & Total Small Stage	E5
	F	Large	Stage	Audio	Main Stage Audio	F1
			Stage	Lighting	Main Stage Guest Lighting	F2
			Stage	Video	Main Stage Video	F3
			Stage	Lighting	Main Stage Lighting	F4
			Traders	Bar	Bar	F5
	G	Medium	Total festival	Total festival	Total Festival	G1
			Stage	Total stage	Second Stage Total	G2
			Stage	Lighting	Second Stage Dimmable Lighting	G3
			Stage	Lighting	Main Stage Lighting	G4
			Traders/stage	Bar/total stage	Bar and Total Small Stage	G5
	H	Major	Stage	Audio	Main Stage Audio	H1
			Stage	Lighting	Main Stage Lighting	H2
			Stage	Lighting	Main Stage Guest Lighting	H3
			Stage	Lighting	Main Stage FOH Lighting	H4
			Stage	Video	Main Stage Video	H5
2011	I	Large	Traders	Traders	Ring of Traders	I1
			Traders	Bar	Bar	I2
			Infrastructure	Tour buses	Main Stage Tour Buses	I3
			Infrastructure	Other	Crew Catering	I4
	J	Large	Infrastructure	Campsite	Production Campsite 1	J1
			Infrastructure	Campsite	Production Campsite 2	J2
			Infrastructure	Other	Materials Recovery Facility (MRF)	J3
	K	Medium	Total festival	Total festival	Total Festival	K1
			Stage	Total stage	Second Stage Total	K2
			Traders	Traders	Ring Of Traders	K3
			Traders/stage	Bar/total stage	Bar and Total Small Stage	K4
	L	Major	Traders	Bar	Bar	L1
			Infrastructure	Tour buses	Main Stage Tour Buses	L2
	M	Medium	Stage	Total stage	Second Stage Total	M1
			Traders	Traders	Ring of Traders	M2
			Traders	Traders	Ring of Traders	M3
2012	N	Large	Infrastructure	Other	Crew Catering	N1
			Stage	Total stage	Second Stage Total	N2
			Traders	Bar	Bar	N3
			Stage	Lighting	Main Stage Lighting	N4
			Stage	Lighting	Main Stage Guest Lighting	N5
			Stage	Audio	Main Stage Audio	N6
			Stage	Video	Main Stage Video	N7
			Stage	Other	Main Stage 'Local'	N8
			Stage	Total stage	Mainstage total	∑ N4-N8
	O	Medium	Stage	Stage	Stage Left Distribution Point	O1
			Stage	Stage	Stage Right Distribution Point	O2
			Stage	Stage	Main Stage Total	∑ O1-O2
			Stage	Stage	Second Stage Total	O3
			Infrastructure	Campsite	Campsite Lighting	O4
			Infrastructure	Offices	Production Offices	O5
			Traders	Traders	Ring of Traders	O6
	P	Medium	Total festival	Total festival	Total Festival	P1
			Stage	Stage	Main Stage Total	P2
			Traders	Traders	Ring of Traders	P3
	Q	Major	Stage	Lighting	Main Stage Lighting 1	Q1
			Stage	Lighting	Main Stage Lighting 2	Q2
			Stage	Lighting	Main Stage Lighting 3	Q3
			Stage	Lighting	Main Stage Lighting Total (excl. guest)	∑ Q1-Q3
			Stage	Lighting	Main Stage Guest Lighting	Q4
			Stage	Lighting	Main Stage FOH Lighting	Q5
			Stage	Audio/Video	Main Stage Video & FOH Audio	Q6
			Stage	Audio	Audio	Q7
			Stage	Audio/Video	Main Stage Guest A/V	Q8
			Stage	Total stage	Main Stage Total	∑ Q1-Q8
			Traders	Bar	Bar	Q9
	R	Medium	Traders/stage	Traders/stage	Traders and Total Small Stage	R1

Table 13 - Description of systems monitored

Data collection depended initially upon liaising with organisers and power providers, both on and off site, in order to gain access all areas passes and well as to ensure that the researcher's involvement did not provide any complications for festival staff. In practice this simply meant waiting for the crew to be ready, meaning that waiting times were incorporated into the research methodology. Being able to be flexible around the needs of production staff proved essential to cultivating a working relationship, as these staff will be busy in the run up to the event.

The dataloggers can only be installed on three-phase split-cable systems. In preparation for the events, a dialogue between the researcher and the production staff meant that split-cable systems were able to be identified prior to arrival on the site. However, last minute alterations to the cable layouts can occur on site, meaning that the scope of data collection could only be confirmed once on site. In practice, the generator layout was always as the researcher expected it to be, so no last minute corrections in data focus were required.

4.3 Practical implications of the methodology

Using split-core current transformers is a very simple, safe, and easy way to monitor power systems. The fact that it is non-invasive means that it is a flexible method, and that the installation and removal processes are quick and simple. It requires no supervision from festival staff, provided the equipment is not installed within the generator casing. This is an important point to consider, as this research focuses on real time data at a real festival, operated by real people, where energy security is paramount. Production staff, such as lighting, audio, video and power engineers, will be at their busiest just before and just after the festival, which coincides with the installation and removal of monitoring equipment, so non-invasive measurements that require little or no interaction with production staff is preferred over a method requiring invasive measurements. This was especially true at the start of the research during the pilot year whilst a working relationship was still being established.

The major drawback for the method is that it only measures current and cannot measure the voltage in the same circuit. It therefore cannot accurately measure power in the system, or voltage uniformity. A working voltage of 230V was assumed in order to calculate power (kW) and energy (kWh) demand. Onsite inspections of generators showed that the generators operated close to this value, although an error 5% should be expected around this value.

Figure 13 - Generator display showing line-neutral voltage of 232 volts

The data acquisition approach had to overcome problems such as weather, security and the physical demands of the equipment. For each system, four current transformers and one datalogger were required. Individually these items represented no problems, but collectively their weight and volume meant that a private vehicle would be required to visit each festival and install the equipment, and that once on site not all dataloggers could be carried by the researcher to install all at once. This meant that data records would appear staggered when analysed after the event. In order to deal with this, the loggers were typically programmed to activate as of 1200 on the Wednesday to allow for a large period of installation. This excess period of recording prior to the event allowed the researcher to install the loggers over time, and also took account of potential delays caused by festival staff, if staff interaction was necessary.

Disregarding these practical considerations, it is worth highlighting the novelty of this approach. Short time interval monitoring is an entirely novel concept at music intervals, and this research represents the first time any data of this kind has been compiled. At the beginning of the PhD, this approach had not been employed by the industry. In the final year of the PhD, the researcher carried out research on behalf of the Green Festival Alliance with the intention of advising participating festivals, and the industry as a whole, on how their festivals were performing from an energy efficiency perspective. The data recorded was incorporated into a wider collection of data that used by the GFA, such as diesel consumption or kWh usage in specific generators, and an industry led prototype datalogger built into specific generators to record generator performance as a whole (e.g. output voltage, power factor, oil pressure, generator temperature, etc). The only other source of data that would have been similar to that gathered in this thesis would be the generator dataloggers. These ran in parallel with the researchers study on system R1 in 2012,however these prototype loggers failed to record data. As a result, the data gathered in this thesis represents the only collection of data of its kind; minute by minute readings covering the majority of power systems employed at music festivals, gathered over the course of 4 seasons.

The failure of industry generator dataloggers in 2012 also highlights the adverse conditions that the equipment must work in. Greenfield music festivals operate outdoors in rural environments with little to no shelter for the generators and cabling, whereas the dataloggers used were designed to operate in areas where large electrical cables typically reside, namely in indoor environments with machinery with large power requirements. These locations are expected to be dry, clean and stable in comparison to a potentially wet, muddy and temporary festival environment. During the course of the research, complications were encountered with the dataloggers, however the issue of equipment failure was factored into the study programme in order to allow for any failures in data collection to be addressed in subsequent years. These complications are discussed below.

In year one, one datalogger was lost due to a failure to collect the logger before the deconstruction of the nearby stage began. This logger was placed upon the stage. As a result, all loggers since this point have been installed as close to the generator or distribution point as possible, as the generators and distribution points are removed much later than the stage itself. The logger was subsequently retrieved later in the season.

In year two, two dataloggers were damaged by excessive rain, and one loggers battery depleted midway through the recording process. The loggers damaged by rain were rendered inoperable, with no useful data. The datalogger which failed due to battery issues only represented one of the three phases monitored for that system, allowing for an extrapolation of further data to be suggested for analysis (see appendix B for further details). Within budgetary constraints, additional waterproofing was applied in reaction to the waterlogging problem in year two, and no further problems were encountered.

No problems were encountered in year three.

In year four, two loggers suffered an internal system failure, and failed to record data. The results for this system have been estimated in order to analyse the total consumption for the generator in question.

In addition to these individual issues, other problems were encountered with the equipment during the research:

- Connectors for the DENT CTs were easily damaged, and over the course of a season many of these connectors frayed and detached from the wire. This was easily fixed outside of a recording period using wire strippers and connecting the bare CT wire to the datalogger, however if this were to happen during an event it would mean a loss of data in one phase.
- Poor connectivity between DENT dataloggers and Elog software. All data was eventually retrieved, however these units connected using serial ports, and were often difficult to connect to. This was found to occur on multiple computers with the Elog software, suggesting an issue with either the DENT range, or just the units used in this research.

4.4 Interaction with festival industry

A great deal of time was spent interacting with festival practitioners, employees and contractors. Festival stakeholders were involved in the process in order to gain practical insight into how the research can be of immediate practical use to those within the industry. This occurred through attendance and presentation at key industry events that allowed for discussion to occur regarding the research and its use to festival professionals. This included contributing to industry events organised by A Greener Festival and Julies Bicycle, as well as presenting at similar events for the Green Festival Alliance, and collaboration in the creation of an industry guide to power provision at events, published by the Green Festival Alliance (Johnson, Marchini et al, 2012) and launched at the UK Festival Awards in 2012. In addition to this public dissemination of data, meetings with organisers on and off site were routinely carried out during the research in order to provide them with the data gathered from their events, and to cultivate a dialogue through which issues and concerns could be raised.

In addition to these interactions with organisers and other bodies, on site interactions were carried out in the form of semi-structured interviews in order to address specific items of concern. These used open-ended questions in order to allow for the interview to adapt and change in line with any new themes that arise during the course of the interview. These interviews are based around predetermined topics and questions, however the manner and order in which they are carried out can be modified depending upon the interviewer's perception of what seems most appropriate. This flexibility also applies to the wording of the questions themselves, as well as their inclusion in the survey, with the interviewer being allowed to omit or include questions as deemed appropriate (Robson, 2007).

While not a key part of the data collection and analysis of the thesis, these interactions led to a great deal of discussion regarding the application of the research, and how the research can be continued upon the conclusion of this thesis. These interactions formed a strong relationship with festival staff, without which this work could not have been undertaken.

4.5 Summary

This chapter has described the methodology used to collect short time interval energy data at music festivals within the research. The methodology represents a flexible method of data collection that can be implemented upon any system where three individual phase cables are accessible, most commonly found with powerlock cables. The method relies upon an assumption of constant voltage, established through consultation with power providers to be 230 volts. Spot checks throughout the festival show this value to be an acceptable estimate, however the lack of voltage measurement is the primary disadvantage of the method.

Chapter four has outlined the electricity data acquisition system, identifying which systems were monitored and when. These systems represent a piece of each festival, and as a group are the largest dataset of their kind. The dataset contains systems from stages, traders and infrastructure, and as a result allows the research to study power use across a typical festival site.

The application of CT monitoring to festival power systems is a novel technique that provides a unique insight into how power use varies throughout a music festival, and analysis of the data collected can be used to identify systematic trends in power demand at festivals, which can in turn be used to identify opportunities for emission reduction.

Chapter 5 – Data analysis methodology

Introduction

Having previously discussed carbon footprint methodology and the practical methodology used for this study, chapter five focuses on the methodology for data analysis in order to satisfy research objective two, which is to use short time interval measurements to analyse the power consumption of festival subsystems. Primary data consists of three phase current demand, the timestamp associated with this demand, and the artist performance schedule. Secondary data was collected through existing power meters for festivals that had access to power from the national grid. This data was provided in the form of kWh on an hourly or half-hourly basis.

In order to allow for cross comparison, both primary and secondary data required processing. Primary current demand was collected through monitoring the three separate phase demands, along with the neutral current. The current demand presented throughout this thesis is the summation of the demand recorded in each phase.

$$I_T = I_{L1} + I_{L2} + I_{L3}$$

Equation 9 - Three phase current assuming equal voltage

To convert this to a measure of power or energy use (kVA, kW or kWh) requires data regarding the voltage profile over the same time span. As this data was not available, demand is expressed in terms of current rather than power or energy. Secondary power data gathered through existing national grid power meters was assumed to be constant during the duration of each reading. While this is unlikely to be the case, estimating in any other way would provide false results. Each reading was extrapolated backwards in time, as the reading at 14:00 would represent power usage from 13:00 until 14:00. It was then assumed that these systems would operate at a constant voltage of 230V, based on aforementioned site inspections. Under this assumption, the kWh values provided were converted into Amp-hours. From here it was assumed that demand was constant over the duration of the reading. While this is unlikely to be the case, estimating in any other way would provide misleading results.

For direct comparison between any two datasets load factor was used rather than the absolute values so that trends in smaller systems would be just as evident as those in larger systems. Load factor is a measure of average demand against maximum demand, but can also be expressed as an instantaneous load factor, using the instantaneous current rather than the average current.

$$Load\ Factor = \frac{I_{Avg}}{I_{Max}}$$

Equation 10 - Load factor

The purpose of this analysis is to establish a standardised method for analysing energy consumption at music festivals. If a methodology can be established, then it can be used by event organisers and power providers to evaluate their own performance against benchmarks, and use this data to improve their energy efficiency and reduce their GHG emissions.

The following chapter discusses types of analysis that could be incorporated into the analysis of the data, and provides a tool for future research in this field. This approach allows researchers to frame an electrical subsystem at a festival so that any two systems may be compared, as well as allowing comparisons to regular concerts or events.

5.1 Energy analysis in other premises based studies

Energy efficiency has become widely desirable during the past 30 years, with it being described as a “win-win” situation for consumers through reducing both expenditure and “negative externalities associated with energy use” (Allcott & Greenstone, 2012). As a result, energy management and energy analysis have been an emerging field of study in line with the ability to collect and process data becoming simpler through use of smart-meters (Darby, 2006; Venables, 2007; Hargreaves, 2010).

Energy management is an important part of managing anything for which energy is required. Energy use has an associated economic and environmental cost, and therefore energy use should be the subject of constant monitoring and analysis in any large building or estate (Clarke et al, 2008). Among a number of motivations include recognising the effects of interventions and determining energy benchmarks (Lee 2000, Stuart, 2011). A key function of this analysis is to find ways in which the estate may be using energy inefficiently, such as whether equipment with a large power load is active when it is not required.

In a building that uses energy on a daily basis throughout the year, the practicality of this process is obvious. Energy use, and therefore costs and GHG emissions, can be reduced by ensuring wasteful practices are detected when they begin to occur, and can subsequently be prevented. There is however a significant difference between the manner in which an estates energy use is managed and how a festivals energy use is managed. While there may be plenty of variation in what occurs on a property or estate, it is more likely to operate in a systematic fashion, with a set routine for working hours, operational schedules and seasonal variations. By having a 'typical' routine (be it hourly, daily, weekly, etc), the estate can establish what 'typical' energy consumption trends are, and from this baseline seek to improve. Music festivals however are temporary events and on an individual basis are difficult to monitor in the same way for a number of reasons:

- The 'routine' at a festival is much different to that of a building. For a festival stage there will be a particular line-up of artists due to perform over the weekend. Each of these are separate 'users' of the stage and will use energy in their own manner.
- In the built environment it is possible to identify 'events' that occur in a property that indicate a change in energy consumption that does not align with the trend of energy consumption prior to the event. At a festival these events will occur regularly due to the fluctuations in energy use due to having artists arrive on and leave the stage, as well as events occurring due to the production crew performing maintenance upon the stage.
- Every element of a festival is deconstructed after one festival and reconstructed before the next. Because of this, a festival system may have a different power specification from one year to the next.

The two principle analysis techniques for energy use are classified as 'monitoring and targeting' (M&T) and 'measurement and verification' (M&V). M&T is a technique that allows the observer to determine what the situation currently is, and as records build up this data can begin to characterise the regular patterns of consumption and highlight areas of inefficiency and wastage (The Carbon Trust 2010). M&V instead is designed to quantify any savings attained through measures that have already been implemented (Efficiency Valuation Organisation, 2007).

5.1.1 Monitoring &Targeting (M&T) and Measuring &Verification (M&V)

Monitoring and targeting (M&T) works on the principle that 'you can't manage what you don't measure'. The basis of the methodology is to establish the existing pattern of consumption through monitoring the system, and establishing a series of achievable targets based upon this data (BEE, n.d.).

The process for M&T is as follows:

- Establish the structure and expected patterns of use of energy use within the system. The expected patterns for a stage for example will relate to the performance schedule.
- Measure and record energy use within the system.
- Analyse the energy use, correlating it with a separate factor such as external temperature.
- Compare results to similar case studies or appropriate benchmarks.
- Set targets for reduction in line with these comparisons.
- Compare future energy consumption to the previously determined targets.

This is a relatively straightforward process provided that the correlation with other factors is based on an appropriate model, and the reduction targets are achievable. The reduction targets can be determined in relation to either past performance or in relation to expected performance. Past performance targets are useful for large changes, such as global GHG emission targets that are created relative to emissions in 1990, whereas expected performance targets are relative to an expected value based upon consumption models that can be used to determine the relationship between separate factors in a system. The model used depends upon the circumstance the system in question finds itself in. Once a model has been selected, then the expected performance can be predicted, and feasible reduction targets can be determined.

In comparison to M&T, measurement and verification (M&V) is a process designed to allow users to evaluate the impact of a known intervention upon energy consumption. Where M&T establishes current consumption and predicts future consumption, M&V instead establishes post-event consumption and compares it to pre-event consumption. The advantage of this method is the presence of the known event, and the fact that before and after results can be directly compared.

Both M&T and M&V are useful techniques, but neither of these approaches is entirely appropriate for this study. Reliable M&T will require a significant quantity of data amassed over a long time period to determine what the expected consumption would be, and reliably identify areas of waste that can be targeted. Considering the limited time available for monitoring at each event, and the expected variability of festival systems, then this technique will not be able to produce a reliable projection for future power consumption for any festival system other than the one it has just monitored. M&V is outside of the scope of this research as it is not within the control of the researcher to implement any new energy saving measures on the site. The potential to predict the impact of any of these reductions would also require a significant margin for error due to the aforementioned variability. Both methodologies may be used when comparing successive years of the same system, however the end users of each system will vary between years, as will equipment specifications and operation schedules. As a result, it will be not be possible to define a causal connection between the changes in consumption profile between successive years unless there are clearly visible changes that correlate with any known alterations, such as total consumption reducing significantly if the system in question has been significantly downsized.

Beside the practical limitations involved with this research, at the time of writing there was no existing model that could be used to predict energy consumption of festival subsystems. Such a model would be necessary in order to accurately use the M&T and M&V methods described previously. The thesis surveyed 73 systems at 18 events over 7 festivals. These systems consisted of a number of groups, of which lighting provided the most datasets with 20. With this sample size, it is unlikely that any trends that emerge will produce robust consumption models, although it is a starting point for future research to build upon.

5.1.2 Time series analysis

> "A *time series* is a collection of observations generated sequentially through time. The special features of a time series are that the data are ordered with respect to time, and that successive observations are usually expected to be dependent. Indeed, it is the dependence from one time period to another which will be exploited in making reliable forecasts."
>
> *Vandaele, 1983*

The above quote both describes what a time series is, and highlights the notion that datapoints in the time series will have some form of dependency and causality with neighbouring datapoints. Given this dependency between readings, the patterns that are present in previous results may be able to predict future results. This idea has been explored with M&T and M&V, however both of these methods are based on the idea that consumption can be predicted through the use of other variables that have a direct influence on consumption, and can be considered deterministic.

Determinism is the principle that all actions and events are the result of a number of conditions in place at the time of the event (Soanes, Spooner et al, 2001). In principle, electricity demand for any festival system is deterministic, as demand is the result of a series of appliances being activated and deactivated to clear and definable levels. However, the range of variables influencing the use of these appliances (see table 14) suggests that consumption should instead be modelled as a stochastic system instead. A stochastic system is considered to consist of random variables. While these variables may individually be deterministic, the quantity and complexity of these variables means that a system can be said to appear to exhibit stochastic behaviour. The stochastic time series model will instead be a function of time, rather than any external variables. In order to accurately analyse the time series, the base characteristics of the series must be determined, such as determining trends which are evident in the series, whether the series is stationary or non-stationary, and whether the series exhibits multiple functions (Vandaele, 1983; Box, Jenkins et al, 2008).

The objectives of time series analysis, as described by Vandaele, are:

1. ***to obtain a concise description of the features of a particular time series process;***
2. ***to construct a model to explain the time series behaviour in terms of other variables and to relate the observations to some structural rules of behavior (sic);***
3. ***based on the results of (1) or (2), to use analysis to forecast the behavior (sic) of the series in the future based upon a knowledge of the past. From (1) we assume that there is sufficient momentum in the system to ensure that past and future behavior (sic) will be the same. From (B) (sic) we have more insight into the underlying forces of the time series process and can exploit these to obtain more accurate forecasts; and***
4. ***to control the process generating the series by examining what might happen when we alter some of the parameters of the model, or by establishing policies that***

> ***intervene only when the process deviates from a target by more than a prescribed amount."***

This process is the theoretical model upon which both M&T and M&V are based. M&V operates under pre-existing models and is free to skip objective 1, whereas M&T will often create a unique model for a unique circumstance. As previously discussed however, the forecasting found in objective 3 is not possible due to the time series only being analysed after the event. Subsequent events may exhibit consumption similar to the forecasts, however these forecasts are based upon systems that may only share a geographical location and nothing else, so it cannot simply be said that a model created in one year can be applied to the next. In the context of GHG emissions resulting from power provision at music festivals, objective 4 can be interpreted to mean the control of these emissions as a result of the time series analysis, a topic that shall be discussed in chapter seven. The analysis methodology instead focuses on objectives 1 and 2, and the creation of a technique that can model consumption at festivals, even though the potential for forecasting in objective 3 is limited by the practical constraints of a festival.

5.2 Modelling consumption

Deterministic models for expected electricity consumption are based upon energy consumption being related to other variables. For the generic subsystems monitored in this study, the influencing factors are listed below:

Stages	Stage lighting	• *Quantity of lighting equipment* • *Equipment specification* • *Equipment durability* • Weather conditions • Patterns of usage for lights (controlled by performers lighting technician) • Performance setlist • Artist performance schedule
	Stage audio	• *Quantity of audio equipment* • *Equipment specification* • *Equipment durability* • Weather conditions • Number of performers and instruments • Performance setlist • Artist performance schedule
	Stage video	• *Quantity of video equipment* • *Equipment specification* • *Equipment durability* • Weather conditions • Artist performance schedule
Traders	Traders	• *Number of traders* • *Size of traders* • *Type of traders* • *Equipment specification* • Weather conditions • Customer demand patterns • Artist performance schedule for nearby stages
Infrastructure	Campsite	• *Facilities available in the campsite* • *Size of campsite* • *Quantity of equipment located in the campsite. This will mostly be lighting and cleaning facilities, but in staff campsites may include power for temporary offices.* • *Equipment specification* • Weather conditions • Customer demand patterns

Table 14 - Variables influencing power demand

The influencing factors above are separated into two groups. Those in italics represent factors which will be constant over the course of the weekend, and those not in italics are variable[6]. Of the variable factors, only weather conditions, performance schedule and the number of performers and instruments can be accurately described for the purposes of comparison, as the others are all either unquantifiable, or are difficult to accurately measure on a short-time basis over the course of the weekend, such as customer demand for cleaning facilities.

Weather conditions are worthy of study, as temperature, level of light, wind speed and direction, cloud cover and rainfall will all have an influence on energy demand in different systems. Audio demand may vary in relation to the wind, overcast skies may change the light demand, and low temperatures may mean that equipment is used as a source of heat, or high temperatures may mean that equipment is turned off to avoid overheating, whilst also increasing demand on cooling systems. However, weather data collection was not viable due to the cost and impracticality of installing a temporary weather station on site. Data from nearby weather stations was not considered given that data from anywhere that wasn't specifically from the site itself would again limit the potential to draw clear correlations.

The quantity of performers and instruments was assumed to have little bearing on the A/V demand, given that the primary power demand would be upon the audience facing amplifiers, rather than any equipment used by the artists. This was found to be correct, as no useful correlation was found between demand and the quantity of performers or instruments. While it can be seen that performers with more instruments or more members can require more power than performers with fewer instruments or members, the reverse can also be seen as well.

[6] The quantity and specification of equipment can change due to headline acts providing their own equipment in addition to the standardised stage rigs. These headliner systems should be considered separately from the standardised rigs if possible, as their performance is not indicative of the stage at other periods in time.

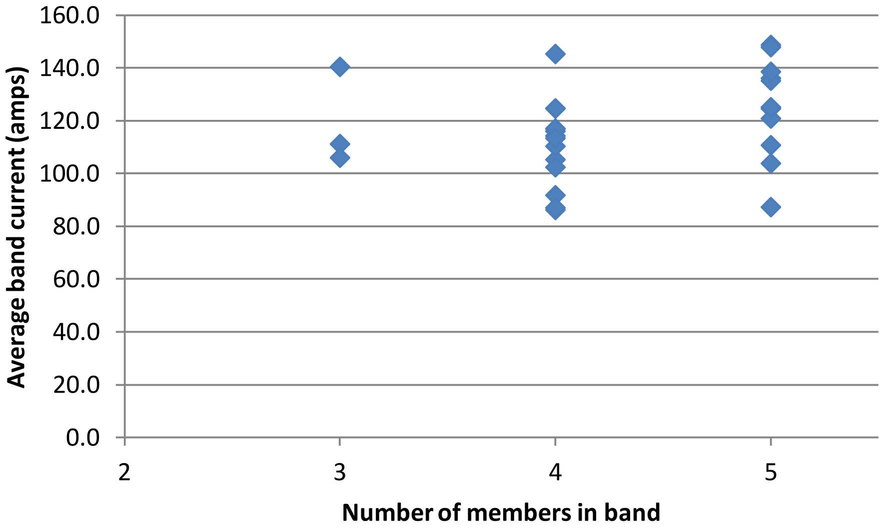


Figure 14 - Band current vs number of band members (Festival C)

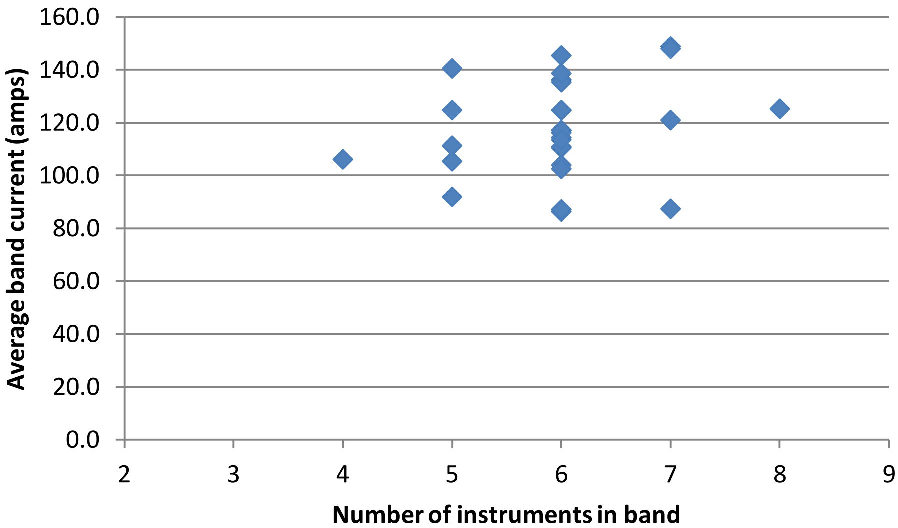


Figure 15 - Band current vs. number of band instruments (Festival C)

Discounting the weather conditions and the artist & instrument quantities, the only variables left for comparison are the performance schedule, and the timestamp for each datapoint. The operations and performance schedules are best described as 'events' or 'interventions' when attempting to describe their nature in each dataset.

Intervention analysis is the study of the impact of special events or circumstances on a given dataset (Box, Jenkins & Reinsel, 2008). M&V is a form of intervention analysis, focusing on an intervention in energy demand. Intervention analysis has been used extensively elsewhere to determine the impact of specific definable events, such as the success of advertising campaigns (Mulhern, 1990), the impact of policy change (Box & Tiao, 1975) and relationship between the tourism demand and public perception of specific locations (Min et al, 2010). This type of analysis is applied to time series where data may be affected by external events in a manner that will disrupt the pre-existing pattern. These interventions take the form of either steps or pulses (Box & Tiao, 1975, Box, Jenkins & Reinsel, 2008), where a step function represents a permanent change in behaviour after the incident and a pulse function represents the effects of an intervention that will deteriorate over a period of time. The mechanics unique to the system in question need to be considered in order to determine whether an incident is described through a step or pulse function, and that direct inspection of the data may be of use when deciding.

These step and pulse functions are a construct designed to mathematically describe the trends shown in the data, which can be seen through visual inspection. Visual inspection of the data allows the observer to gain insight into large amounts of data in a manner that tabulated data cannot. Data visualisation however is a subjective process rather than objective and can be interpreted in a number of ways. A popular example of this is the artwork of Edgar Rubin which can be viewed to be either a vase or two faces.

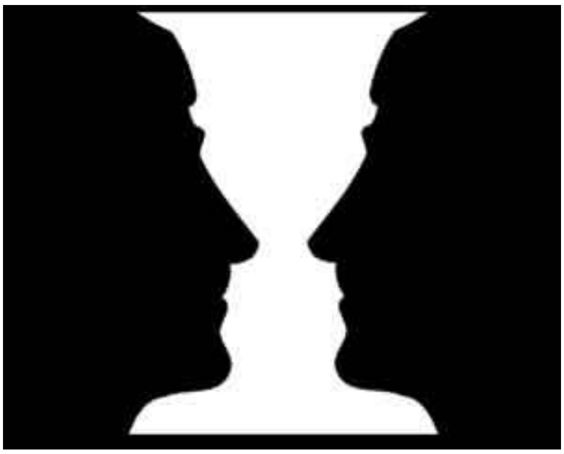


Figure 16 - Rubin's vase

The interpretation of the data will be influenced by the observer's own knowledge and opinions, meaning that any knowledge gained from the analysis is a reflection of the prior knowledge rather than a purely objective interpretation. In the example above, with only the image to analyse there is no way to determine if the image depicts two faces, or a vase. A simple taxonomy can be applied to the image however in order to determine which of these options the image is. Continuing from the example of Rubin's vase, an example of the taxonomy could be:

> *Is the white area widest at the top and bottom of the image? If so, it is two faces, if not, it is a vase.*

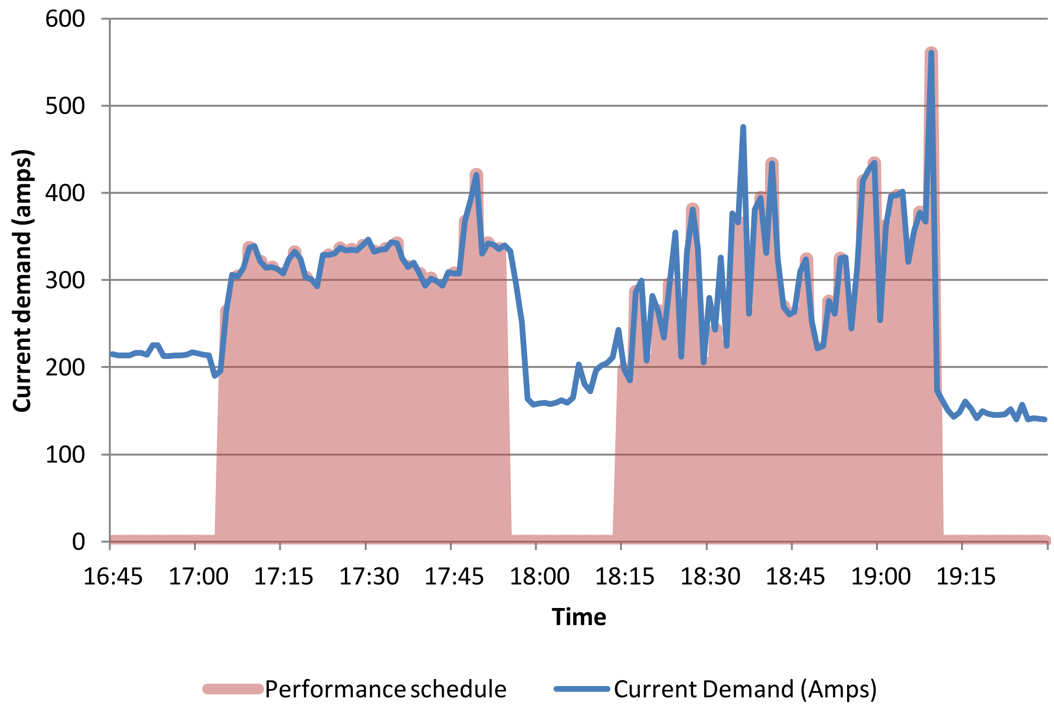
This single question allows the image to be classified in an objective manner on the basis of its shape. This approach can also be applied to time-oriented data, with a taxonomy described by MacEachren (Kehrer, 2007; MacEachren, 1995; Müller& Schumann, 2003) so that the visual analysis would answer the following questions:

- Existence of data element: Does a data element exist at a specific point in time?
- Temporal location: When does a certain data element (e.g. pattern) exist in time? Is there any cyclic behaviour?
- Time interval: How long is the time span from the beginning to end of the data element?
- Temporal texture: How often does a data element occur?
- Rate of change: How fast does a data element change over time, and/or how much difference is there from element to element?
- Sequence: In what order do the data elements appear?
- Synchronisation: Are there data elements, which exist together?

This method provides observers with a simple list of elements to pass judgement on within the dataset. Whilst each question is still open to interpretation, it compartmentalises the task of visual analysis so that each element can be investigated individually, and ensures that observers will all be attempting to observe the same parameters.

5.3 Creating an appropriate analysis methodology

The analysis methodologies discussed previously are all relevant to this study, however in their original form, none are directly applicable to this work. Both M&T and M&V require energy consumption models that accurately describe energy consumption based upon at least one separate factor, such as external air temperature. No such single factor exists for all festival systems, as they are the result of a number of electrical components (these will vary festival to festival, and may also change during the festival) being operated in line with custom (traders), weather (traders, all stage systems), and with personal preference. An example of this can be seen below where the lighting demand for two successive performers appears markedly different through visual analysis, yet yields similar average demands. As a result they are best described as stochastic systems rather than deterministic systems.



	Average demand (amps)	Estimated energy total (kWh)
Band 1	325	50
Band 2	317	53

Figure 17 - Concurrent band performances, displayed graphically and quantitatively

Stochastic consumption models for premises and buildings for energy analysis are constructed either through using models from comparable sites, or from the estimates created using large quantities of previous consumption data. These models are formed on the assumption that the building operates with a set routine for operational schedules, seasonal variations and weather variations. These routines create a standard schedule of operation, such as operating Monday to Friday, 0800 until 1800, with a clearly defined staff population and equipment specification. In comparison, each festival is a temporary system with its own unique schedule of performances, as well as a number of hours when the main arena is open or closed to the audience in a similar manner to the opening and closing of an office. As a result, each festival subsystem monitored has a day and night period, and where applicable will also have additional 'band' periods when artists are on stage, and 'changeover' periods between performances. These are based around the appropriate performance schedule.

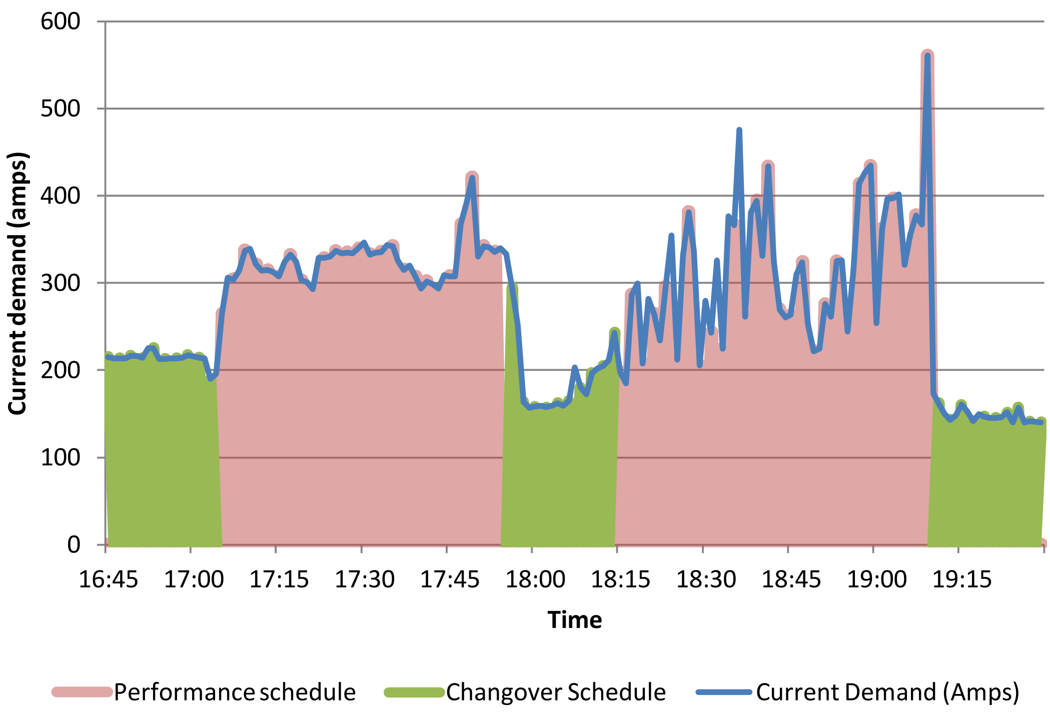


Figure 18 - Example of performance schedule and changeover schedule

The notion of band and changeover is an attempt to determine how the performance schedule influences the power demand of any systems that would be affected (primarily only the stage systems), however it also fits into the ideologies of event detection in M&V and the incident analysis of time series analysis. The presence of these artists would be expected to be the key variable that prevents stage systems from having a standard load profile with demand remaining relatively constant, and therefore easily describable, over the course of the weekend. As it stands however, there is no published data regarding the manner in which artistic performances influence stage demand. Non-stage systems will be compared to their most appropriate stage performance schedule, however there is little causal connection between the demand of non-stage systems and the artistic performance schedule elsewhere on the festival site.

The information gathered through visual analysis can be quantified and incorporated into this analysis. Referring back to Rubin's vase (figure 16) the shape of the image can provide information on the object in question. For example, if it is known that the central object in the image is larger in the middle of the image than it is at the top or bottom of the image, then the image can be described as depicting the two faces rather than the vase. Alternatively, this relationship can be described through an indicator;

$$Vase\ Indicator = VI = \frac{Width_{midpoint}}{Width_{top}}$$

Equation 11 - Example for using indicators to quantify visual data

In this scenario, if the vase indicator value is greater than 1, then the object is a vase. If not, then the object is two faces. Conversely, this technique can be applied to the load shape profiles collected in this thesis, allowing for quantitative evaluation and classification of the load profile of festival systems. These metrics quantify the shape of the load profiles displayed over the course of the weekend, and can be used to describe any festival subsystem with regard to its overall performance.

The first series of indicators are load factors (LF) for each time period. The load factor is the ratio between the average demand and maximum demand for the period in question.

Indicator designation	Alternative indicator designation	Calculation
α_1	LF_{Day}	$\alpha_1 = \frac{I_{Avg,day}}{I_{Max,day}}$
α_2	LF_{Night}	$\alpha_2 = \frac{I_{Avg,night}}{I_{Max,night}}$
α_3	LF_{Band}	$\alpha_3 = \frac{I_{Avg,band}}{I_{Max,band}}$
α_4	$LF_{Changeover}$	$\alpha_4 = \frac{I_{Avg,changeover}}{I_{Max,changeover}}$
α_5	$LF_{Weekend}$	$\alpha_5 = \frac{I_{Avg,weekend}}{I_{Max,weekend}}$

Table 15 - Load factor profile indicators

The second series of indicators are modulation factors (MF) for each time period. The modulation factor is the ratio between the minimum demand and the average demand for the time period in question.

Indicator designation	Alternative indicator designation	Calculation
α_6	MF_{Day}	$\alpha_6 = \frac{I_{Min,day}}{I_{Avg,day}}$
α_7	MF_{Night}	$\alpha_7 = \frac{I_{Min,night}}{I_{Avg,night}}$
α_8	MF_{Band}	$\alpha_8 = \frac{I_{Min,band}}{I_{Avg,band}}$
α_9	$MF_{Changeover}$	$\alpha_9 = \frac{I_{Min,changeover}}{I_{Avg,changeover}}$
α_{10}	$MF_{Weekend}$	$\alpha_{10} = \frac{I_{Min,weekend}}{I_{Avg,weekend}}$

Table 16 - Modulation factor profile indicators

I_{min} was determined using the 5th percentile for the day period, 0th percentile for night and changeover, and the 100th non-zero value for band. The percentile method was not used for the band performance period due to the some systems spending the majority of the festival at 0 amps, thereby skewing the results. The non-zero value method ensured all systems would be appropriately represented. The 5th percentile was used to remove erroneous results due equipment malfunctions or power cuts, as these would not be representative of the entire daytime period. The 0th percentile was used for night and changeover periods as these are periods that theoretically should have as low a demand as possible. Visual inspection also showed no evidence of equipment malfunctions or power cuts in these time periods in any dataset.

The third series of indicators are peak demand uniformity coefficients (PDUC). The PDUC compares the maximum demand of one time period with the maximum demand of another.

Indicator designation	Alternative indicator designation	Calculation
α_{11}	$PDUC_{Band-day}$	$\alpha_{11} = \frac{I_{Max,band}}{I_{Max,day}}$
α_{12}	$PDUC_{Changeover-day}$	$\alpha_{12} = \frac{I_{Max,changeover}}{I_{Max,day}}$
α_{13}	$PDUC_{Band-weekend}$	$\alpha_{13} = \frac{I_{Max,band}}{I_{Max,weekend}}$
α_{14}	$PDUC_{Changeover-weekend}$	$\alpha_{14} = \frac{I_{Max,changeover}}{I_{Max,weekend}}$
α_{15}	$PDUC_{Day-weekend}$	$\alpha_{15} = \frac{I_{Max,day}}{I_{Max,weekend}}$
α_{16}	$PDUC_{Night-weekend}$	$\alpha_{16} = \frac{I_{Max,night}}{I_{Max,weekend}}$

Table 17 - Peak demand uniformity coefficient profile indicators

The fourth series of indicators are baseload uniformity coefficients (BUC). The BUC compares the minimum demand of one time period with the minimum demand of another.

Indicator designation	Alternative indicator designation	Calculation
α_{17}	$BUC_{Day-band}$	$\alpha_{17} = \frac{I_{Min,day}}{I_{Min,band}}$
α_{18}	$BUC_{Day-changeover}$	$\alpha_{18} = \frac{I_{Min,day}}{I_{Min,changeover}}$
α_{19}	$BUC_{Weekend-day}$	$\alpha_{19} = \frac{I_{Min,weekend}}{I_{Min,day}}$
α_{20}	$BUC_{Weekend-night}$	$\alpha_{20} = \frac{I_{Min,weekend}}{I_{Min,night}}$

Table 18 - Baseload uniformity coefficient profile indicators

The fifth series of indicators are impact factors (IF). Impact factors compare the average demand of one time period with the average demand of another.

Indicator designation	Alternative indicator designation	Calculation
α_{21}	$IF_{Night-day}$	$\alpha_{21} = \frac{I_{Avg,night}}{I_{Avg,day}}$
α_{22}	$IF_{Band-day}$	$\alpha_{22} = \frac{I_{Avg,band}}{I_{Avg,day}}$
α_{23}	$IF_{Changeover-day}$	$\alpha_{23} = \frac{I_{Avg,changeover}}{I_{Avg,day}}$
α_{24}	$IF_{Changeover-band}$	$\alpha_{24} = \frac{I_{Avg,changeover}}{I_{Avg,band}}$
α_{25}	$IF_{Day-weekend}$	$\alpha_{25} = \frac{I_{Avg,day}}{I_{Avg,weekend}}$
α_{26}	$IF_{Night-weekend}$	$\alpha_{26} = \frac{I_{Avg,night}}{I_{Avg,weekend}}$

Table 19 - Impact factor profile indicators

The PDUC, BUC and IF are designed to describe the relationship between different time periods at a festival. The use of all three indicators ensures that the system user has a more detailed description of the patterns of use than they would with just one of the indicators. LF and MF are to be used to describe each time periods relationship between the average, maximum and minimum demands.

These metrics are based upon the principles of load profiling in line with the work of Nazarko & Styczynski (1999), Chicco et al. (2001) and Ferreira (2009), who have all worked to quantify the use of load shape profiles. These metrics are dimensionless, and are descriptors that allow for quick comparisons between any systems, and provide empirical values that can be compared to the observations gained through visual analysis. The metrics characterise the average, baseload and peak demand for all five time periods, as well as their impact upon one another. Much of the literature on load profiling relates to characterising customer consumption patterns and classification (Chicco 2001, Yu, Yang et al, 2006; Elexon (n.d.), with little mention of its use on an individual system or property for diagnosing poor energy performance. In light of this, the work of Ferreira (2009) proved useful as it focuses upon individual systems for the purpose of energy performance rather than load profile characterisation.

Time period	Hours included
Weekend	1030 Friday until 2359 Sunday
Day	1030 until 2300 for each day
Night	0200 until 0800
Band	Anytime a performer is on stage
Changeover	Periods in between artists being on stage

Table 20 - Times used for each time period

The daytime period has been defined as 1030 until 2300 on Friday, Saturday and Sunday, and has been applied to every system for a uniform comparison. 1030 – 2300 was chosen as the most appropriate times as this encompasses the daytime operations. The night period has been defined as 0200 until 0800. The artist performance period was typically confined by the hours 1100 and 2300, and in order to determine an appropriate night period that can be shared between all systems, the standard deviation and mean for the 2300 – 1100 period was tested in comparison to a number of smaller variants. The optimum period was found to be 0300 – 0700 due to this period having the smallest average standard deviation and mean, however it was decided that this period was too short to represent the night period. The 0200 – 0800 period exhibited similar results to the 0300 – 0700 period, but allowed for an additional two hours of data to be included. Limiting the overnight period to this six hour period limits the potential for the overnight dataset being contaminated by daytime operations. This ensures that it is specifically the 'overnight' period that is under investigation rather than the period which is not daytime, as it is specifically the night operations that this period is concerned with, not the gradual change between night and day operations.

Overnight time period	Average Standard Deviation	Average Mean
2300-1100	44.69	120.30
0000-1000	37.72	112.50
0100-0900	31.18	107.00
0200-0800	24.28	103.26
0300-0700	21.99	102.25

Table 21 - Average standard deviation and mean for various night periods

These factors and indices will form the core of the analytical techniques used in this work, being used to analyse energy performance and identify opportunities to improve operational efficiency, as well as systems suitable for alternative power provision for subsequent years.

The final element to the time series analysis is investigating the fraction of time spent at each load factor through percentile analysis. Percentile analysis determines common load factor ranges for a system. If these common loads correspond with specific time periods during the festival, then this can also provide an opportunity to use an alternative power source during these periods. Optimal power solutions can then be tailored to match supply with demand more effectively. This is true for all levels of load factor, not just low load factors. This again is a method of quantifying that which may be viewed through visual analysis for the purposes of cross comparison and categorisation.

5.3.1 Interpreting the load profile indicators

The load profile indicators quantify what would otherwise be visual data in order to characterise the load profiles, and subsequently identify opportunities for demand reduction. The following bullet points can be used as a guide to interpret the indicators:

- Load factor and modulation factor (α_1 through α_{10}) are a measure of average demand against maximum and minimum demand. Values close to 1 indicate little variation throughout the time period in question, and consistent levels of demand allow for greater fuel efficiencies provided the generator is sized appropriately.
- Peak demand uniformity coefficient and baseload uniformity coefficient (α_{11} through α_{20}) compare the maximum and minimum demands of individual time periods. They can be used to highlight during which time periods the maximum or minimum demands occur during the festival, and how individual time periods compare with one another. With PDUC a value of 1 shows that the maximum demands of the two time periods are equal. BUC values are not as simple, as values of either 0 or 1 can show this as well if zero demand is recorded in either time period. Both the PDUC and BUC suffer from being comparisons of singular values, however these values are the values that ultimately determine the power requirements, as the maximum demand dictates the size of power supply, and minimum demand can indicate periods of demand that can be met through alternative sources.
- Impact factor (α_{21} through α_{26}) compares the average demands of individual time periods. This is the most robust measure of cross period performance as it is not reliant upon singular maxima and minima, and can therefore be used to identify patterns of behaviour in energy demand. These indicators have been constructed with a bias towards the daytime and band periods as these are the periods during which demand should be greatest due to this being when the artists are performing. As a result, for stage systems values below 1 should be expected, however for systems designed for night use like campsite lighting, values greater than 1 should be expected. The impact factors can be used to highlight operational inefficiencies in this manner. For instance, if α_{21} for stage lighting is 1, it shows that average night demand is equal to average daytime demand, and barring exceptional circumstances this shows that equipment has been left active when it does not need to be.

In terms of immediate uses for the load profile indicators, they can be used to determine the consistency of demand (α_1 through α_{10}), the location of peaks and troughs in demand (α_{11} through α_{20}) and current patterns in energy use between different time periods (α_{21} through α_{26}). The values collected through the research can be used to create initial benchmarks for performance due to the novelty of having this data available, although these values will not represent firm guidelines due to the limited size of the dataset.

5.4 Generator capacity analysis

Of the systems monitored, a number represented the total demand placed upon 8 individual generators that also had their maximum capacity recorded as well. All other records did not represent the total demand placed upon the generator, and were therefore not applicable to this section of research. These records will be analysed as a comparison between estimated kW demand and rated maximum kW supply.

$$Loading\ percentage = \frac{kW_{Recorded}}{kW_{Rated\ maximum}}$$

Equation 12 - Generator loading percentage

The rated maximum of real or active power (kW) is calculated by multiplying apparent power rating (kVA) of the generator by a power factor of 0.8, again assumed as constant through visual inspection of generator display panels throughout the research.

$$Real\ Power = Apparent\ Power\ \times Power\ Factor$$

Equation 13 - Relationship between real power and apparent power

These figures are also used to estimate fuel consumption on a minute by minute basis. Fuel consumption was estimated using the fuel consumption rates provided by Diesel Service & Supply (2009) and Perfect Fuel (2009) and using the following selection criteria.

$$x = \begin{cases} P \times f_{1/4} & 0 \leq P < 0.25.P_T \\ P \times f_{1/2} & 0.25.P_T \leq P < 0.5.P_T \\ P \times f_{3/4} & 0.5.P_T \leq P < 0.75.P_T \\ P \times f_1 & 0.75.P_T \leq P \leq P_T \end{cases}$$

Equation 14 - Fuel consumption selection criteria for emissions estimates where x is the fuel consumption (litres), P is the power demand (kWh), P_T is the generators maximum power, $f_{1/4}$ is the fuel consumption rate at ¼ load (l/kWh), $f_{1/2}$ is the fuel consumption rate at ½ load (l/kWh), $f_{3/4}$ is the fuel consumption rate at ¾ load (l/kWh), and f_1 is the fuel consumption rate at full load (l/kWh).

This model is designed to estimate the fuel consumption of each system in a more accurate way than assuming a constant rate of fuel consumption per kWh, or a standard rate of emission per kWh. The results produced by this model are intended to be used for comparative purposes only, but can also be used to estimate the financial cost attached to each generator, as well as the potential savings if a smaller generator is used instead. This process is designed to operate solely on the basis of optimising the power supply for recorded demand, and therefore does not take into account the power that was not used at the event, but was necessary to budget for when sizing the generators prior to the event. The process is strictly a comparison of what was used, and what was supplied, and should not be relied upon solely for generator sizing in subsequent years.

5.5 Analysis methodology summary

Chapter 5 has described the methodology for analysing short time interval energy data from festivals, which can be used to satisfy research objective two. The core of the analysis methodology is the quantification of the load profiles using the load profile indicators. These indicators allow for systems to easily be compared with one another, and for large datasets to be analysed collectively. These quantitative results can be used to analyse individual events, but can also be used to identify patterns of behaviour found across multiple datasets, and subsequently identify systems that operate differently to this behaviour in order to identify opportunities for demand reduction through changes in operational procedures rather than changing equipment to low energy equivalents.

The use of load profile indicators is designed to quantify that which is seen with the naked eye, and allows for easy cross comparison between systems. These indicators can be applied in order to create a basis for comparison, and therefore a basis for evaluation and benchmarking. Initial benchmarks shall be proposed based on these indicators despite the limited sample size, as this is the first time that any such benchmarks can be proposed, and despite the sample size, the argument for “fuzzy accuracy” rather than “false precision” put forward by Harper (2010) suggests that something is better than nothing.

In order to reduce GHG emissions the level of demand or the quantity of fuel must be reduced. The indices can highlight periods of comparatively high or low demand. If these periods can be proven to by systemic, then alternative power supplies to account for these periods may be worthwhile. For example, should one festival have a systematic period of 2 hours during which demand was entirely greater than the 75th percentile, then having the generator running to accommodate this period will reduce the generators efficiency the rest of the day. As a result, it may be desirable to downsize the generator, and have second generator available to provide this additional power. Conversely, periods with low demand may be powered through smaller generators or through temporary renewable energy technologies (TRET).

The chapter concludes with a methodology for analysing generator fuel consumption in order to identify the fuel consumption associated with the load profiles. This analysis is likely to be one of the most effective arguments for practical changes in festival power provision, although these results should be considered to be indicative rather than absolute, and should also not be considered in isolation. They are comparisons of supply and demand, with no consideration for a number of other factors that will influence their results, such as the equipment specification or the needs of the systems users.

Chapter 6 – Load profile results

Introduction

This chapter details the data gathered in depth in order to describe the patterns of demand found at these events. These patterns are quantified through the analysis metrics presented in chapter 5, and where appropriate visual analysis is used to provide further explanation. This work makes up the majority of the chapter, with a series of summary conclusions at the end that will be used in chapter 7, where the observations and findings of this chapter will be applied to the practicalities of power provision at a music festival, and how this data can be used to reduce GHG emissions at festivals.

The metrics created in chapter 5 were designed to put a series of standardised numbers to what was previously a subjective judgement. Table 22 contains the summary statistics of the indicators. While these numbers are novel, they are of little use, as collating data from systems that share nothing other than geographical location does not account for the different functions that each system faces, and that logically there will not be a 'one size fits all' model that encompasses all systems, given the variety of systems monitored for the study. The breadth of data however meant that it was possible to examine each subset in more detail.

This chapter refers to a number of individual systems by their unique reference, found in both table 13 and appendix c.

The data is analysed by system function. Where possible, stage equipment is broken down to its function, most commonly lighting, audio and video. If all of the subsystems on a given stage are monitored, these are then combined to provide comparison with stages which do not have these systems separated. The stages vary in sizes, depending upon the festival in question. The noted practice was that the larger a stage was, the more of a breakdown between these systems there was. For main stages at large and major festivals, it was possible to gather data on all three elements, whereas on smaller stages the breakdown between these systems would typically occur later in the circuit, using combined core cabling that was incompatible with the monitoring equipment. The only exceptions to this rule were stages in which the lighting was provided through powerlock cabling, but other systems were provided through combined core cabling, again preventing data collection.

Sections 6.1 through 6.7 are all presented in a similar format to one another, as each is designed to convey data and findings from each subset of data in the same manner. As a result, these sections appear repetitive. The overall conclusions from the results presented in these sections can be found in section 6.10, as well as discussion regarding using these metrics for benchmarks. The values presented in sections 6.1 through 6.7 can be used as benchmark values as well for each type of system. Section 6.10.1provides a guide on how to apply these values.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α1	LF Day	0.49	0.51	0.18	0.03	0.88	73
α2	LF Night	0.61	0.65	0.24	0.00	1.00	72
α3	LF Band	0.48	0.50	0.16	0.03	0.73	50
α4	LF CO	0.52	0.57	0.19	0.05	0.79	50
α5	LF Overall	0.42	0.43	0.16	0.02	0.73	73
α6	Mod Day	0.53	0.60	0.24	0.00	0.84	73
α7	Mod Night	0.64	0.74	0.29	0.00	1.00	72
α8	Mod Band	0.56	0.66	0.28	0.00	0.94	50
α9	Mod CO	0.55	0.66	0.28	0.00	0.90	50
α10	Mod Overall	0.49	0.45	0.39	0.00	2.99	73
α11	Peak band-day	0.99	1.00	0.04	0.87	1.10	50
α12	Peak CO-day	0.84	0.91	0.20	0.26	1.00	50
α13	Peak band-Fri/Sun	0.99	1.00	0.04	0.87	1.10	50
α14	Peak CO Fri/Sun	0.83	0.90	0.20	0.26	1.00	50
α15	Peak Day-Fri/Sun	1.00	1.00	0.01	0.92	1.02	73
α16	Peak Night-Fri/Sun	0.48	0.45	0.29	0.00	1.00	73
α17	Base Day-Band	0.93	0.87	1.52	0.00	11.02	48
α18	Base Day-CO	1.20	0.63	4.16	0.00	29.36	48
α19	Base Fri-Sun-Day	0.79	0.79	0.39	0.00	2.24	73
α20	Base Fri-Sun-Night	1.04	1.03	0.53	0.00	4.22	71
α21	Impact Night/Day	0.61	0.50	0.60	0.00	3.98	73
α22	Impact Band/Day	1.09	1.06	0.12	0.93	1.53	50
α23	Impact CO/Day	0.97	0.97	0.21	0.24	1.47	50
α24	Impact CO/Band	0.90	0.93	0.21	0.21	1.29	50
α25	Impact Day/Fri/Sun	1.19	1.18	0.18	0.49	1.61	73
α26	Impact Night/Fri/Sun	0.63	0.60	0.36	0.00	1.97	73

Table 22- Summary statistics for load profile indicators across all recorded datasets

6.1 Stage lighting systems

Load Factor

Table 23 contains the summary statistics of the load factor profile results. Table 24 presents the full results for load factor indicators for all lighting systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α1	LF Day	0.36	0.43	0.18	0.03	0.58	20
α2	LF Night	0.43	0.36	0.32	0.00	0.95	20
α3	LF Band	0.40	0.48	0.18	0.03	0.62	20
α4	LF CO	0.40	0.40	0.20	0.05	0.69	20
α5	LF Overall	0.30	0.34	0.14	0.02	0.47	20

Table 23- Summary of stage lighting load factors

Table 23 shows that load factor, on average, does not vary much over the course of the festival. There is little observable difference between load factor during the day between band performances and changeover periods (see figure 19). There are however clearly some systems which do not conform to these average values, as there is a significant dispersion amongst the night load factor, with values almost equal to both 0 and 1 being returned. The minimum values are populated by guest lighting systems designed for headlining artists only. These systems are therefore due to be inactive for the majority of the festival, and these minimal loads have impacted upon the statistics above. Figure 19displays the load factor values for generic lighting systems.

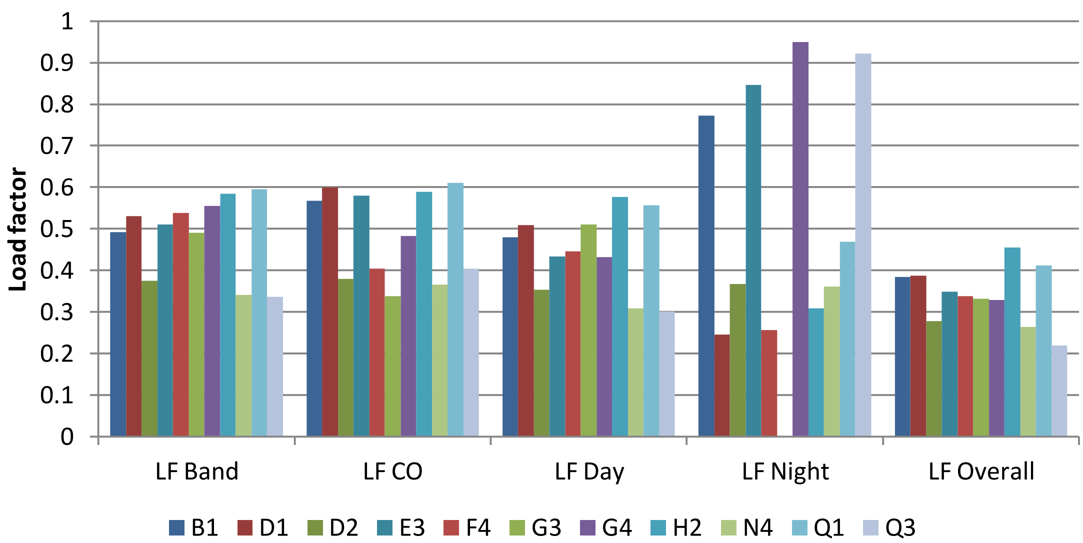


Figure 19 - Load factor values for generic stage lighting systems (FOH and guest lighting not included)

In each time period, there are two main levels of performance. For example during band performance, α_3 is either between 0.3 and 0.4 or 0.5 and 0.6. While it is positive that there are consistent bands for each load factor, there is no link between those systems in a particular band. The most likely explanation for this that it is a statistical coincidence owing to a small sample size of only 11 systems, and that the overall band of 0.3 to 0.6 for α_3 should be used instead.

The difference between these bandings is only 10% during artist performances, which suggests maximum demand is 10% larger during these artists. This figure is not surprising when the lighting is designed to impress the audience, and this increase may simply be due to these systems having additional equipment assigned to being used for periods of maximum demand, such as headline artists. Lighting load factors as a whole may be prone to reduced load factors when compared with other systems, due to equipment being reserved for specific periods.

Night load factor analysis for lighting can be seen to be unreliable. The largest load factors are found in the night period, but values equalling zero are also found in this period. Through visual analysis it can be seen that many of these systems exhibit a consistent pattern of usage overnight, although at times they may be activated or tested (e.g. tested for a specific performance the following day). These test periods will greatly reduce the load factor, as average demand will be affected slightly, but maximum demand will increase significantly during this time. As a result of their lowered average demand, a single test period greatly reduces the overall load factor, leading to results of up to 0.95, as well as results as low as 0.25. This is a problem that can be seen in all systems relating to the performance stages, although it is not evident in systems that provide services for the public, such as traders or campsites.

Night load factor also has a problem on the basis of how it is calculated. The ideal scenario for a power system at night is to record negligible current demand, with no variations, returning a load factor value close to 1. However if zero demand is recorded, again with no variations, then the load factor is 0. Both of these indicate consistent demand. A revised metric for load factor analysis during periods of potential zero consumption was created in order to standardise results so that both high and low load factors are given equal weighting. The metric was however rejected on the basis that it revealed less information than the original value. For example, α_2 values of 0.2 and 0.8 provide more information regarding consumption patterns, and would both be standardised to a value of 0.6 in the α_{27} metric.

$$\alpha_{27} = \theta = \begin{cases} 2 \times (0.5 - \alpha_2) & \alpha_2 < 0.5 \\ 2 \times (\alpha_2 - 0.5) & \alpha_2 > 0.5 \end{cases}$$

Equation 15 - Standardised α_2 to show proximity to maximum or minimum values

	α1	α2	α3	α4	α5
System	LF Day	LF Night	LF Band	LF CO	LF Overall
B1	0.48	0.77	0.49	0.57	0.38
D1	0.51	0.25	0.53	0.60	0.39
D2	0.35	0.37	0.37	0.38	0.28
E3	0.43	0.85	0.51	0.58	0.35
E4	0.22	0.86	0.38	0.31	0.44
F2	0.04	0.00	0.04	0.05	0.02
F4	0.45	0.26	0.54	0.40	0.34
G3	0.51	0.00	0.49	0.34	0.33
G4	0.43	0.95	0.55	0.48	0.33
H2	0.58	0.31	0.58	0.59	0.46
H3	0.11	0.19	0.16	0.08	0.11
H4	0.30	0.62	0.33	0.33	0.24
N4	0.31	0.36	0.34	0.37	0.26
N5	0.03	0.00	0.03	0.05	0.02
Q1	0.56	0.47	0.59	0.61	0.41
Q3	0.30	0.92	0.34	0.40	0.22
Q4	0.16	0.01	0.18	0.15	0.11
Q5	0.52	0.62	0.52	0.59	0.47

Table 24 - Stage lighting load factor demand indices

Non-generic lighting systems, such as guest supplies for headlining artists and front of house (FOH) lights, each performed differently. Periodic load factor analysis was of little use for guest circuits (F2, H3, N5, Q4), as the limited time during which they were active meant that all load factors would be low. All values are below 0.2, however there is no consistency regarding how the periodic load factors relate to one another. The period of activity does not impact the FOH load factors in the same manner, but there is still no consistency between load factors of the three systems (E4, H4 and Q5). This is an issue of having a small sample size, and the variance in FOH system usage. System E4 is used at a small festival to provide safety lighting during the night, whereas H4 and Q5 are major festivals that appear to have used the lighting systems at other periods, especially so during the build up to the headlining artists. This suggests there is a disparity in the designation and usage of FOH systems at different sized festivals. All of these systems however show consistent periods of use, with specific periods of extra consumption, suggesting that these periods of extra use are pre-planned and scheduled.

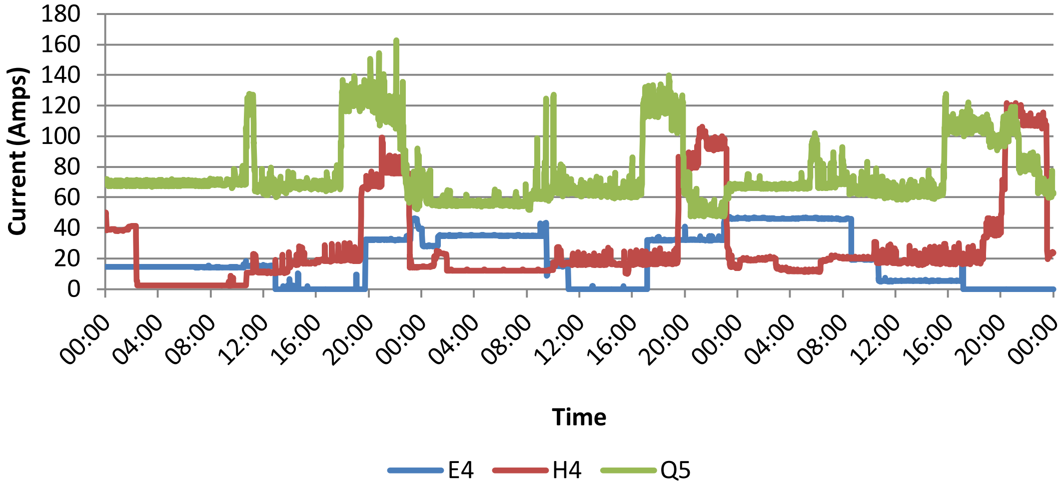


Figure 20 - Load profile for FOH lighting systems (Friday through Sunday)

Modulation factor

Table 25 contains the summary statistics of the modulation factor profile results. Table 26 presents the full results for modulation factor indicators for all lighting systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α6	MF Day	0.39	0.39	0.25	0.00	0.83	20
α7	MF Night	0.53	0.65	0.35	0.00	0.94	20
α8	MF Band	0.37	0.42	0.30	0.00	0.75	20
α9	MF CO	0.42	0.43	0.33	0.00	0.85	20
α10	MF Overall	0.48	0.29	0.67	0.00	2.99	20

Table 25 - Summary of stage lighting modulation factors

Table 25 shows that modulation factor is a highly variable measure of performance, with a large standard deviation, large dispersion, and returns values that exceed the maximum value of 1. Two values exceed an MF of 1, both are weekend factors for guest lighting systems. These values have been reached due to the calculation methods. The minimum values have been calculated using a variety of techniques in order to avoid zero values (see section 5.3). In systems that were active throughout the weekend, this technique was used to eliminate erroneous readings from being used as the minimum value, as, for example, a loss in power would return a value of zero, and it was decided such a scenario should not be used for baseload analysis. Headliner lighting datasets however were regularly drawing zero amps, and as a result of the calculation methods, the minimum value recorded represented the minimum value during use. The periods of zero consumption however were considered for the average demands, and over the course of the entire weekend this allowed the system to have sufficient periods of zero consumption to create a sub-zero average consumption, and therefore an MF over 1.

System	α6 MF Day	α7 MF Night	α8 MF Band	α9 MF CO	α10 MF Overall
B1	0.57	0.71	0.64	0.55	0.29
D1	0.23	0.62	0.22	0.29	0.31
D2	0.20	0.73	0.19	0.35	0.31
E3	0.49	0.48	0.48	0.43	0.36
E4	0.50	0.85	0.00	0.00	0.25
F2	0.83	0.00	0.00	0.00	2.99
F4	0.57	0.00	0.55	0.60	0.58
G3	0.21	0.00	0.00	0.00	0.10
G4	0.24	0.94	0.66	0.69	0.30
H2	0.20	0.36	0.75	0.77	0.22
H3	0.11	0.00	0.00	0.00	0.11
H4	0.28	0.82	0.35	0.27	0.39
N4	0.70	0.42	0.69	0.75	0.27
N5	0.00	0.00	0.00	0.00	1.49
Q1	0.66	0.84	0.74	0.85	0.22
Q3	0.60	0.91	0.60	0.81	0.19
Q4	0.00	0.53	0.02	0.01	0.00
Q5	0.58	0.85	0.60	0.73	0.71

Table 26 - Stage lighting modulation factor values

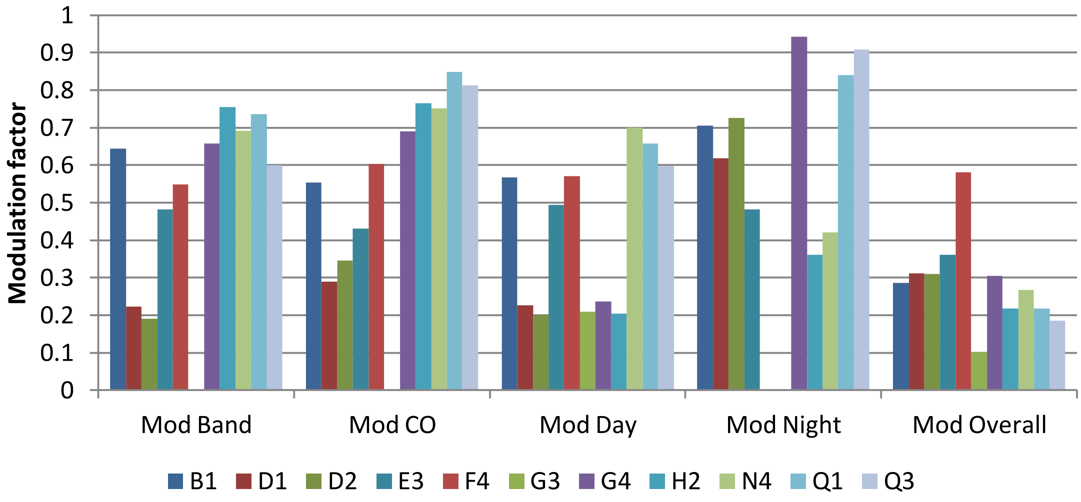


Figure 21 - Modulation factor values for generic lighting systems (FOH and guest lighting not included)

Table 26 and figure 21 also show the variability of readings with the modulation factor. The only areas with consistent results are in the daytime modulation factor α_6, and the overall modulation factor α_{10}. α_6 has a series of values at 0.2, with all other values between 0.5 and 0.7. There is no connection the systems which have performed similarly, suggesting that there is little use in these figures. α_{10} values are mostly in the range of 0.2 to 0.3, and given that the most consistent values for both load factor and modulation factor have been in the weekend profiles, this suggests that the analysis of smaller periods may reduce the sample size too much, especially considering the variable nature of stage consumption (see figure 17).

There is no consistency with the results of the FOH lighting systems, other than at night when modulation factor varies by only 0.03 between the three systems This should be expected, as the night period should be a time where the baseload is close to the average consumption, as the FOH lights should be used for illumination for workers during this time, and nothing else.

As mentioned previously, guest lighting suffers due to the sampling process for calculating modulation factor, and the factor itself is not entirely appropriate for a system with large periods of zero consumption.

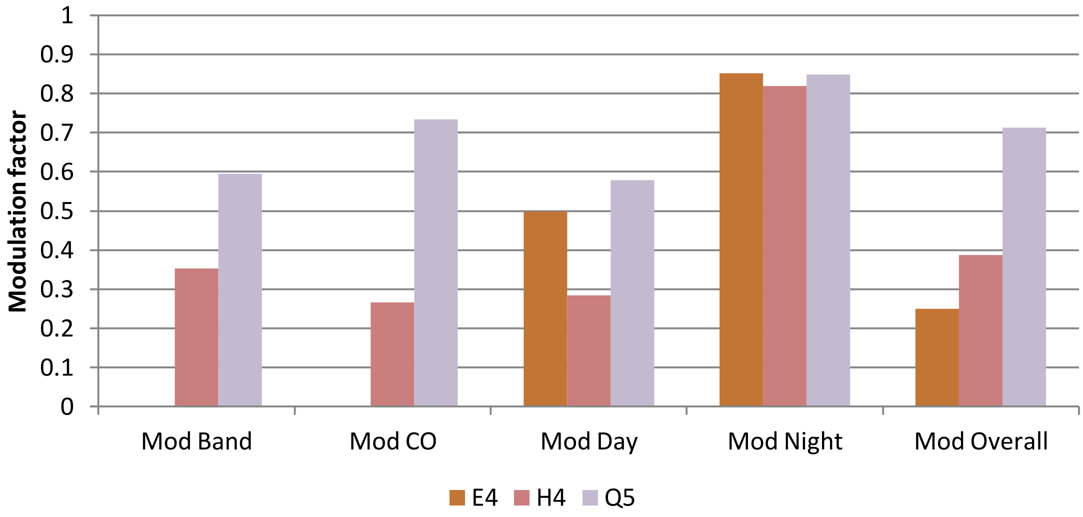


Figure 22 - Modulation factor values for FOH lighting systems

Cross period analysis (PDUC, BUC, IF)

Table 27 contains the summary statistics of the peak demand uniformity coefficient (PDUC). Table 28 presents the full results for PDUC indicators for all lighting systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
$\alpha 11$	Peak band-day	0.99	1.00	0.03	0.87	1.00	20
$\alpha 12$	Peak CO-day	0.82	0.86	0.21	0.26	1.00	20
$\alpha 13$	Peak band-Fri/Sun	0.99	1.00	0.03	0.87	1.00	20
$\alpha 14$	Peak CO Fri/Sun	0.82	0.86	0.21	0.26	1.00	20
$\alpha 15$	Peak Day-Fri/Sun	1.00	1.00	0.00	1.00	1.00	20
$\alpha 16$	Peak Night-Fri/Sun	0.38	0.21	0.34	0.00	1.00	20

Table 27 - Summary of stage lighting peak demand uniformity coefficients

The PDUC metric highlights the areas where peak demand can be expected. In this instance, the peak demand can be expected to occur during the daytime operations, and more specifically during the artists' performances. This is because the values of α_{11}, α_{13} and α_{15} are almost entirely 1, with little deviation from this trend. In comparison, α_{16} (night vs. weekend PDUC) suggests that peak demands are rarely encountered during the night period due to having a consistently low value, although there are outliers of greater value. These outliers are caused by the following:

- Notable spikes in demand in generic lighting systems. These increases in consumption are each for a period of around 2 hours, during which consumption is comparable to regular daytime demand, suggesting that performance tests were underway. The researcher observed these tests occurring at earlier time periods than those indicated in the data, but was not available to observe these at the times highlighted by the PDUC.
- Guest and headliner lighting systems was also tested during these same periods.
- FOH safety lighting being active predominantly at night.
- FOH lighting in other instances was found to have a large constant load throughout the weekend, with the system never falling below 29% loading.

PDUC analysis for changeover periods suffers from the lack of an instantaneous decrease in consumption after an artists' performance. As a result, the peak demand many not accurately reflect the peak demand of the changeover period, but instead the 'leftover' demand from the preceding performance.

System	α11 Peak band-day	α12 Peak CO-day	α13 Peak band-Fri/Sun	α14 Peak CO Fri/Sun	α15 Peak Day-Fri/Sun	α16 Peak Night-Fri/Sun
B1	1.00	0.86	1.00	0.86	1.00	0.20
D1	1.00	0.83	1.00	0.83	1.00	0.79
D2	1.00	0.92	1.00	0.92	1.00	0.40
E3	1.00	0.98	1.00	0.98	1.00	0.21
E4	0.87	0.73	0.87	0.73	1.00	1.00
F2	1.00	0.99	1.00	0.99	1.00	0.00
F4	0.99	1.00	0.99	1.00	1.00	0.59
G3	1.00	1.00	1.00	1.00	1.00	0.00
G4	1.00	0.86	1.00	0.86	1.00	0.11
H2	1.00	0.98	1.00	0.98	1.00	0.88
H3	0.98	0.84	1.00	0.86	1.00	0.98
H4	1.00	1.00	1.00	1.00	1.00	0.18
N4	1.00	0.72	1.00	0.72	1.00	0.45
N5	1.00	0.29	1.00	0.29	1.00	0.00
Q1	1.00	0.85	1.00	0.85	1.00	0.22
Q3	1.00	0.61	1.00	0.61	1.00	0.05
Q4	1.00	0.26	1.00	0.26	1.00	0.11
Q5	1.00	0.93	1.00	0.93	1.00	0.63

Table 28 - Stage lighting PDUC values

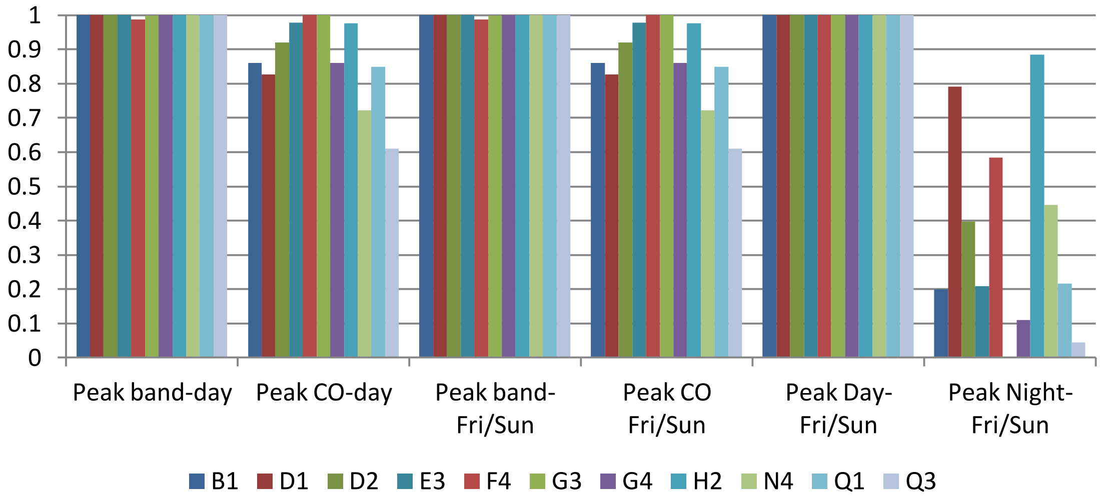


Figure 23 - PDUC values for generic stage lighting systems (FOH and guest lighting not included)

Table 29 contains the summary statistics of the baseload uniformity coefficient (BUC). Table 30 presents the full results for BUC indicators for all lighting systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α17	Base Day-Band	0.57	0.83	0.42	0.00	0.99	20
α18	Base Day-CO	0.42	0.35	0.36	0.00	1.06	20
α19	Base Fri-Sun-Day	0.80	0.91	0.52	0.00	2.24	20
α20	Base Fri-Sun-Night	0.73	1.00	0.49	0.00	1.49	20

Table 29 - Summary of stage lighting baseload uniformity coefficients

	α17	α18	α19	α20
	Base Day-Band	Base Day-CO	Base Fri-Sun-Day	Base Fri-Sun-Night
B1	0.86	0.40	0.40	1.00
D1	0.97	0.84	1.05	1.00
D2	0.99	0.72	1.22	0.82
E3	0.87	0.52	0.59	1.49
E4	0.00	0.00	1.01	0.15
F2	0.00	0.00	2.24	0.00
F4	0.88	0.81	0.77	0.00
G3	0.00	0.00	0.31	0.00
G4	0.28	0.35	0.98	1.01
H2	0.27	0.23	0.84	1.01
H3	0.00	0.00	1.01	0.00
H4	0.75	1.06	1.07	1.00
N4	0.91	0.35	0.33	1.04
N5	0.00	0.00	0.00	0.00
Q1	0.84	0.20	0.24	1.05
Q3	0.89	0.20	0.23	1.07
Q4	0.10	1.00	1.00	1.00
Q5	0.96	0.83	1.12	1.01

Table 30 - Stage lighting BUC values

Baseload uniformity coefficient suffers the same problems as the modulation factor due to the variable minimum loads placed on each system, as well as the selection criteria also lead to some values being greater than 1. As a whole dataset however, the stage lighting systems show that the night baseload can be considered to be minimum level of consumption throughout the festival weekend due to the majority of α_{20} being effectively 1. The exceptions to this trend are as follows:

- Lighting subsets that are deactivated at night, thereby returning a minimum value of zero amps – F2, G3, H3 and N5,
- An entire main stage lighting systems that is deactivated on one night during the observations. Discounting this occurrence, the previous night's values would have provided a BUC value of 1 – F4.

Table 31 contains the summary statistics of the impact factors (IF), table 32, presents the same summary for generic stage lights, and table 33 presents the full results for impact factors for all lighting systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α21	Impact Night/Day	0.53	0.35	0.88	0.00	3.98	20
α22	Impact Band/Day	1.13	1.09	0.13	0.96	1.53	20
α23	Impact CO/Day	0.91	0.97	0.26	0.24	1.35	20
α24	Impact CO/Band	0.82	0.85	0.24	0.21	1.19	20
α25	Impact Day/Fri/Sun	1.28	1.30	0.23	0.49	1.61	20
α26	Impact Night/Fri/Sun	0.50	0.46	0.51	0.00	1.97	20

Table 31 - Summary of stage lighting impact factors

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α21	Impact Night/Day	0.31	0.34	0.15	0.00	0.52	13
α22	Impact Band/Day	1.09	1.07	0.09	0.96	1.29	13
α23	Impact CO/Day	0.95	0.96	0.15	0.66	1.31	13
α24	Impact CO/Band	0.87	0.87	0.12	0.69	1.11	13
α25	Impact Day/Fri/Sun	1.31	1.31	0.09	1.17	1.54	13
α26	Impact Night/Fri/Sun	0.39	0.44	0.18	0.00	0.61	13

Table 32 - Summary of generic stage lighting impact factors

Impact factor is a less variable metric than suggested by table 31, as systems E4 and H3 have much greater average night consumption than they do during the daytime, leading to skewed impact factor values. In addition to these two outliers, the issues previously mentioned regarding zero consumption at night means that some night IF values are zero. The factor is most useful as a measure of how, on average, one period performs in comparison to another. For example, the impact factor suggests that daytime lighting demand on average is 28% greater than average weekend demand, and night lighting demand (between the hours of 2am and 8am) is 50% less than average weekend demand.

Discounting FOH and guest lighting, the results become much more consistent, with standard deviation decreasing in for all impact factors by at least 31%, and as much as 83% in α_{21}. These figures show systematic decreases in demand between artist performances and at night in generic lighting.

FOH and headliner lighting results are difficult to analyse as a group due to the variety of purposes they are required to provide, as the usage of FOH safety lights should be expected to be different to headliner lighting. The only consistent result is that these systems draw more power during band performances than during the day as a whole, suggesting that lighting systems are not as clearly defined as they would ideally be.

	α21	α22	α23	α24	α25	α26
	Impact Night/Day	Impact Band/Day	Impact CO/Day	Impact CO/Band	Impact Day/Fri/Sun	Impact Night/Fri/Sun
B1	0.32	1.03	1.02	0.99	1.25	0.40
D1	0.38	1.04	0.97	0.93	1.32	0.50
D2	0.41	1.06	0.99	0.93	1.27	0.52
E3	0.41	1.18	1.31	1.11	1.24	0.50
E4	3.98	1.53	1.05	0.69	0.49	1.97
F2	0.00	1.13	1.35	1.19	1.61	0.00
F4	0.34	1.19	0.90	0.76	1.32	0.44
G3	0.00	0.96	0.66	0.69	1.54	0.00
G4	0.24	1.29	0.96	0.75	1.31	0.32
H2	0.47	1.01	1.00	0.98	1.27	0.60
H3	1.58	1.34	0.58	0.43	1.06	1.67
H4	0.37	1.07	1.08	1.00	1.27	0.47
N4	0.52	1.11	0.86	0.77	1.17	0.61
N5	0.00	1.12	0.49	0.44	1.55	0.00
Q1	0.18	1.07	0.93	0.87	1.35	0.25
Q3	0.14	1.12	0.82	0.73	1.37	0.19
Q4	0.00	1.13	0.24	0.21	1.44	0.01
Q5	0.75	1.01	1.06	1.05	1.10	0.83

Table 33 - Stage lighting IF values

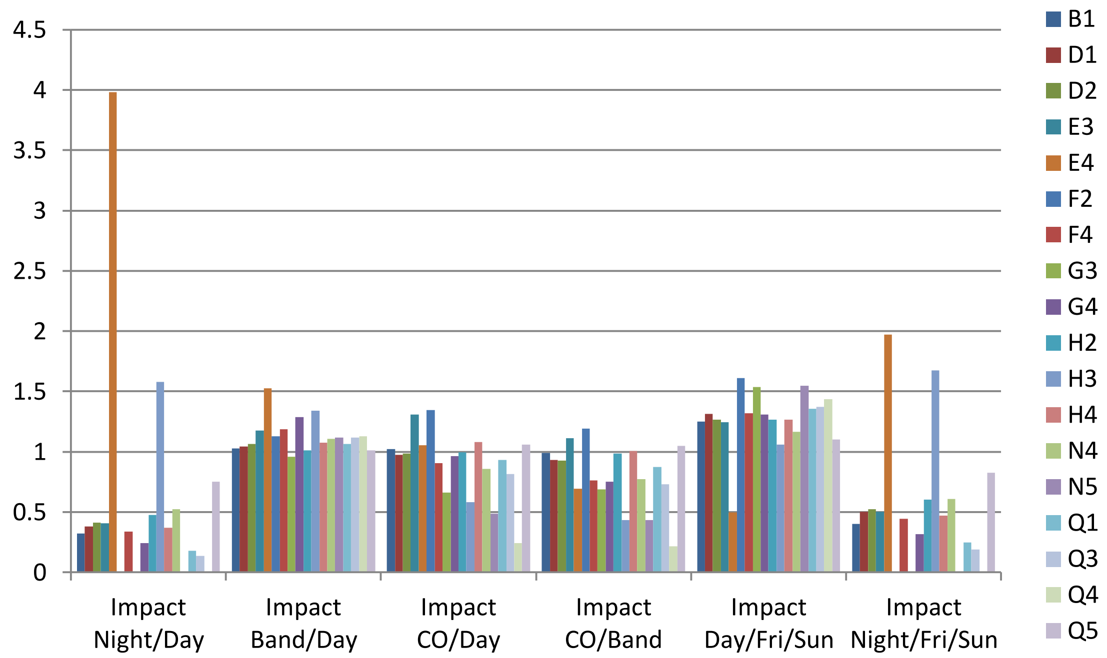


Figure 24 - Impact factor values for all stage lighting systems

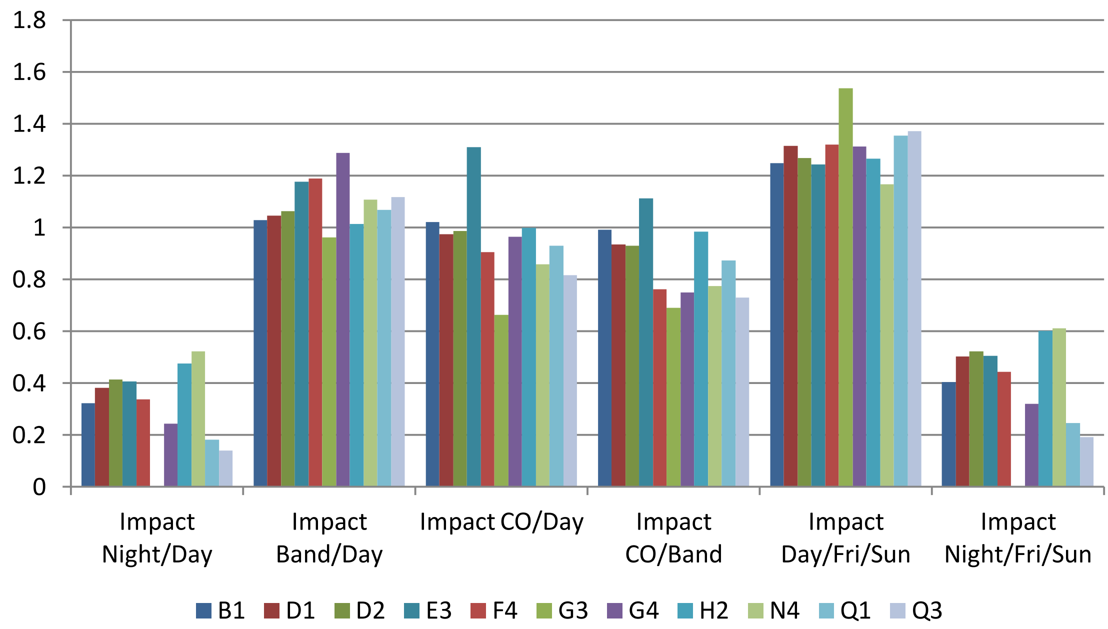


Figure 25 - Impact factor values for generic stage lighting systems

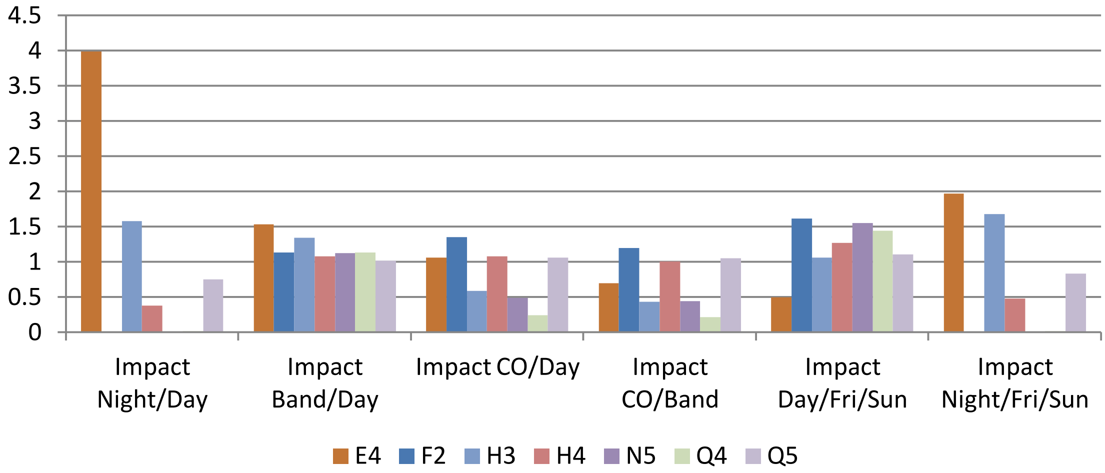


Figure 26 - Impact factor for stage FOH and guest lighting systems

6.2 Stage audio systems

Load Factor

Table 34 contains the summary statistics of the load factor profile results. Table 35 presents the full results for impact factors for all audio systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α1	LF Day	0.44	0.44	0.12	0.28	0.67	7
α2	LF Night	0.76	0.76	0.15	0.49	1.00	7
α3	LF Band	0.48	0.44	0.14	0.30	0.73	7
α4	LF CO	0.58	0.54	0.14	0.40	0.79	7
α5	LF Overall	0.37	0.39	0.11	0.23	0.54	7

Table 34 - Summary of stage audio load factors

Having a standard deviation significantly lower than both the mean and median values suggest that there is consistency with how each audio system performs. Visual analysis of these load profiles supports this idea. Excluding system Q8 which is a guest audio feed, all other systems have clear diurnal variation, with four of these having similar total demand. The two systems not conforming to this trend were the two earliest audio datasets recorded, with all other systems recorded since 2010, suggesting that there may be an emerging usage pattern in the more recent data. The usage of guest audio throughout the day suggests that this system refers to audio systems that every artist would use, rather than one that only the headliners would use, such as a system provided to accommodate a band's own amplifiers for whilst they are on stage.

	α1	α2	α3	α4	α5
System	LF Day	LF Night	LF Band	LF CO	LF Overall
B2	0.67	0.70	0.73	0.79	0.54
D3	0.47	0.49	0.56	0.54	0.44
F1	0.44	0.74	0.44	0.54	0.40
H1	0.45	0.85	0.49	0.40	0.39
N6	0.42	0.76	0.44	0.60	0.32
Q7	0.28	0.80	0.30	0.75	0.23
Q8	0.36	1.00	0.39	0.46	0.24

Table 35 - Stage audio load factor values

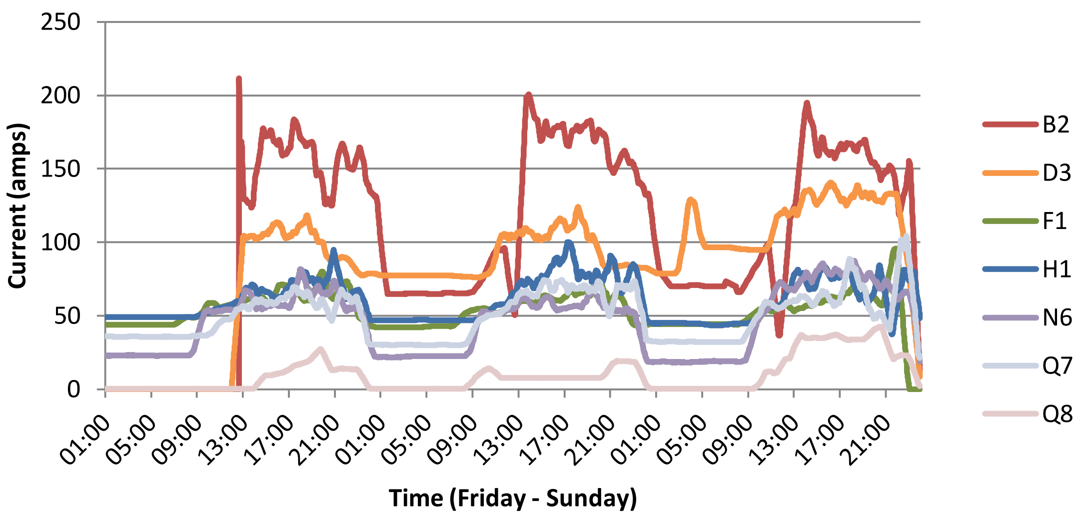


Figure 27 - Hourly rolling average demand for audio systems

Discounting B2 and Q8, the load factor performances are similar for the other five systems, save for some discrepancies due to excessively high or low maximum values in systems D3, H1 and Q7. While only a sample of five systems, the data suggests that at large and major festivals, specific load factor values could be expected in these systems in each time frame. A greater dataset to further prove or disprove this notion would is desirable. The decline in overall load factor with each successive dataset is likely to be a coincidence given the similarity of load profiles.

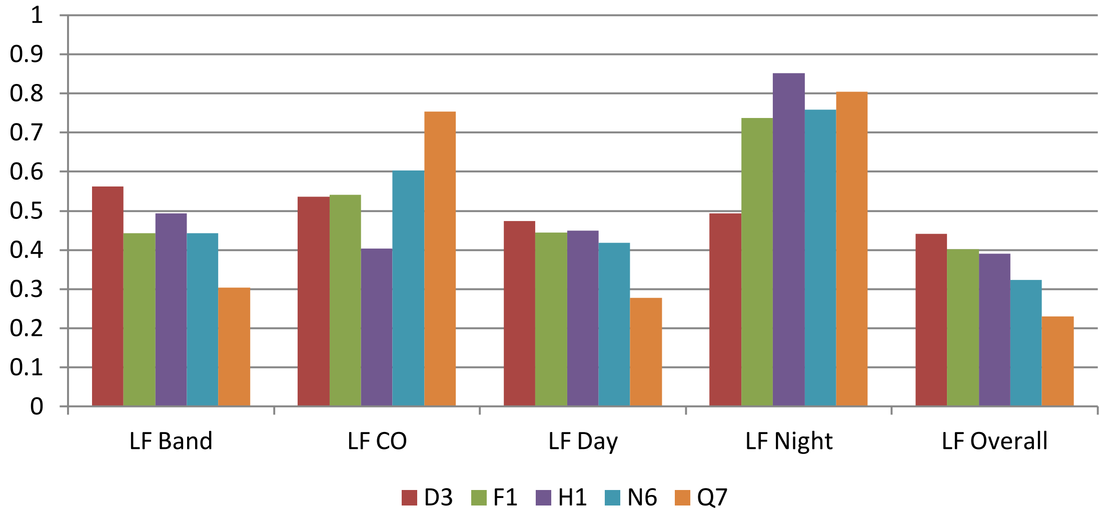


Figure 28 - Load factor for a selection of stage audio systems

Modulation factor

Table 36 contains the summary statistics of the modulation factor profile results. Table 37 presents the full results for modulation factor indicators for all audio systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α6	Mod Day	0.50	0.60	0.29	0.01	0.74	7
α7	Mod Night	0.92	0.95	0.08	0.77	1.00	7
α8	Mod Band	0.67	0.70	0.14	0.39	0.80	7
α9	Mod CO	0.62	0.72	0.28	0.02	0.83	7
α10	Mod Overall	0.53	0.57	0.27	0.02	0.79	7

Table 36 - Summary of stage audio modulation factors

The consistency in baseload demand that can be seen in figure 27 is mirrored in the modulation factors, although again outlier values skew the summary statistics. Daytime modulation factor in B2 is skewed by a single dip in demand on Saturday afternoon, and Q8 has periods of negligible demand during changeover times, thereby reducing the associated modulation factors to negligible levels.

System	α6 Mod Day	α7 Mod Night	α8 Mod Band	α9 Mod CO	α10 Mod Overall
B2	0.19	0.95	0.80	0.64	0.52
D3	0.74	0.86	0.76	0.74	0.79
F1	0.73	0.95	0.74	0.81	0.76
H1	0.51	0.94	0.70	0.60	0.71
N6	0.70	0.77	0.70	0.72	0.36
Q7	0.60	0.95	0.59	0.83	0.57
Q8	0.01	1.00	0.39	0.02	0.02

Table 37 - Stage audio modulation factor values

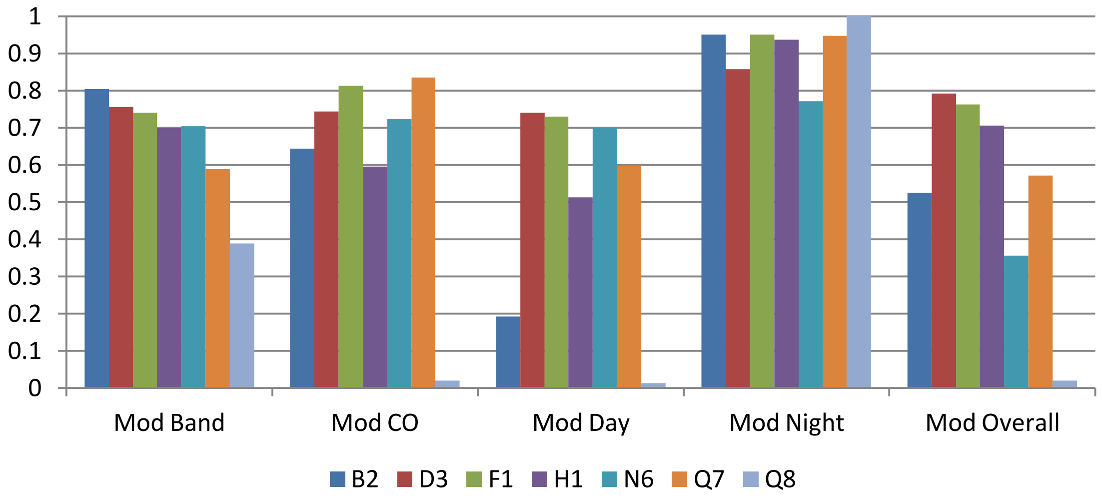


Figure 29 - Modulation factor for stage audio systems

As with load factor, if extreme examples are discounted then the modulation factor results show that specific MF values could be expected in audio systems in each time frame, although again a greater dataset would be beneficial. The sampling techniques used to filter out erroneous values have not been an issue with generic audio systems (Q8 is a guest supply).

Cross period analysis (PDUC, BUC, IF)

Table 38 contains the summary statistics of the peak demand uniformity coefficient (PDUC). Table 39 presents the full results for PDUC indicators for all audio systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α11	Peak band-day	0.97	1.00	0.05	0.88	1.00	7
α12	Peak CO-day	0.74	0.88	0.27	0.28	1.00	7
α13	Peak band-Fri/Sun	0.97	1.00	0.05	0.88	1.00	7
α14	Peak CO Fri/Sun	0.74	0.88	0.27	0.28	1.00	7
α15	Peak Day-Fri/Sun	1.00	1.00	0.00	1.00	1.00	7
α16	Peak Night-Fri/Sun	0.34	0.34	0.26	0.00	0.81	7

Table 38 - Summary of stage audio peak demand uniformity coefficients

	α11 Peak band-day	α12 Peak CO-day	α13 Peak band-Fri/Sun	α14 Peak CO Fri/Sun	α15 Peak Day-Fri/Sun	α16 Peak Night-Fri/Sun
B2	0.92	1.00	0.92	1.00	1.00	0.42
D3	0.88	0.93	0.88	0.93	1.00	0.81
F1	1.00	0.88	1.00	0.88	1.00	0.43
H1	1.00	0.93	1.00	0.93	1.00	0.34
N6	1.00	0.63	1.00	0.63	1.00	0.18
Q7	1.00	0.28	1.00	0.28	1.00	0.17
Q8	1.00	0.51	1.00	0.51	1.00	0.00

Table 39 - Stage audio PDUC values

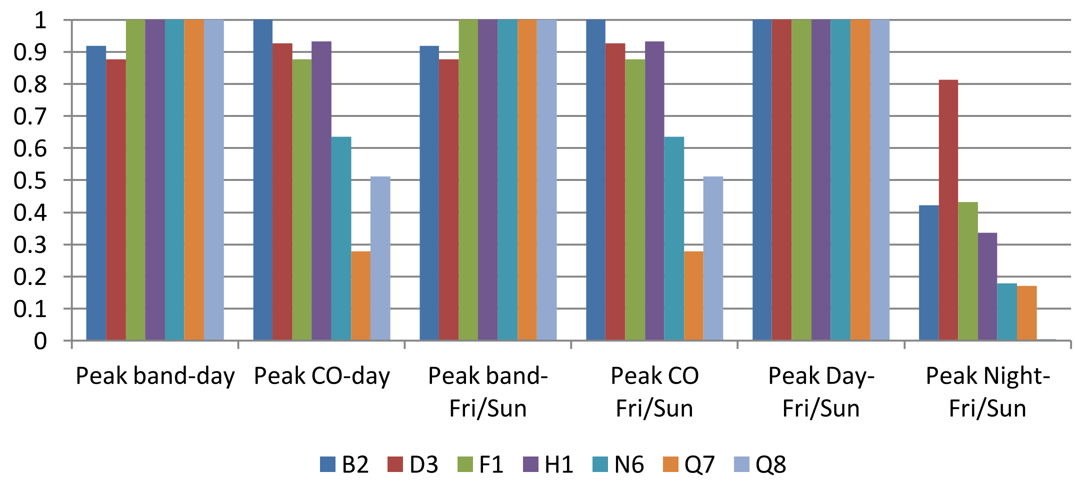


Figure 30 - Peak demand uniformity coefficient values for audio systems

As with lighting, PDUC indicates that the peak values can be expected to occur during the daytime, and during artist performances in particular. Changeover periods experience a variety of peaks with respect to the overall daytime peak, as does the night period. The issues with band performance and changeover performance overlapping is an issue here, as it was with lighting PDUC. This factor however is reversed in system B2, with changeover periods averaging 28 amps more than during band periods. This was not observed in any other system monitored during the research, and no explanation could be provided by practitioners during post-event discussions. Systems H1 and Q7 however demonstrates the opposite pattern of use, with the majority of its changeover periods being lower than the surrounding band periods by an average of 19 and 21 amps respectively. H1 does not show this in the PDUC analysis however due to the overlap of peaks between the performance periods and the changeover periods. These systems have a clear baseload during the changeover period too, and there is clear definition to show standard practice during these periods.

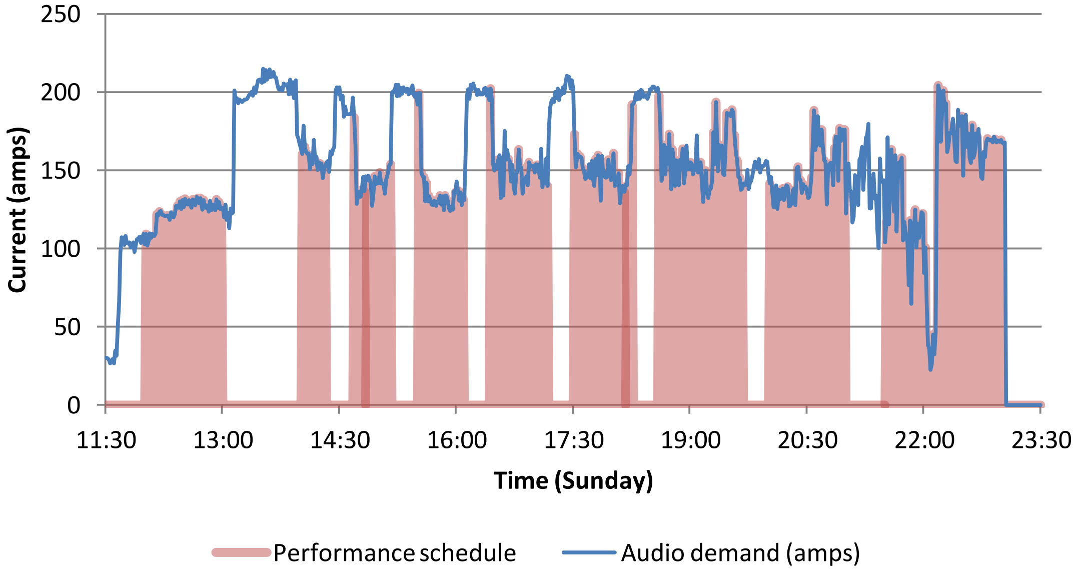


Figure 31 - Audio demand in system B2 with artist schedule

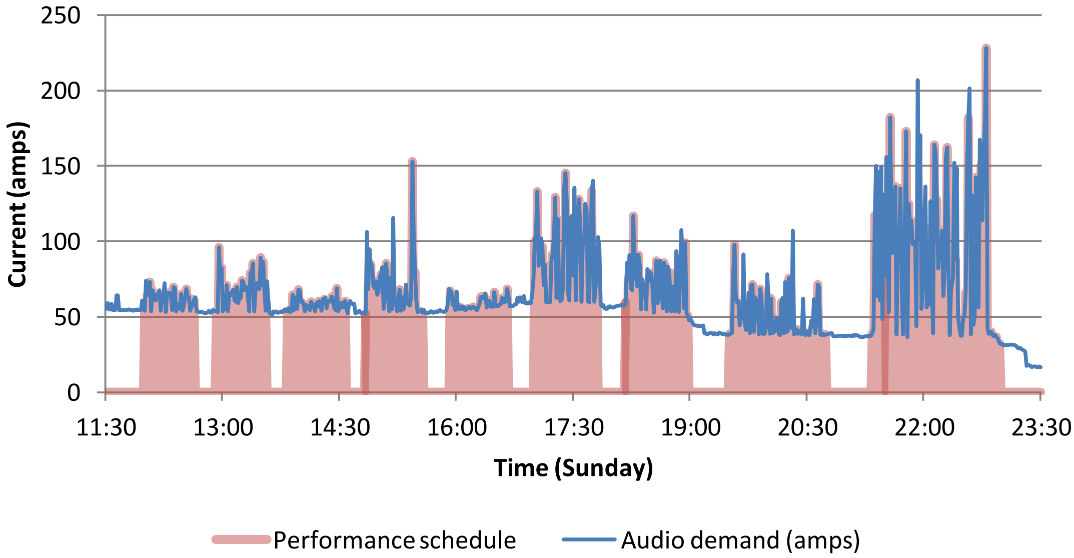


Figure 32 - Audio demand in system Q7 with artist schedule

Audio BUC has the same problem as lighting BUC with variable results due to the selection criteria with different subsets. Discounting B2 and Q8, as done with audio MF, does alleviate this problem, but the dataset as a whole is still shown to be inconsistent. Measures α_{19} and α_{20} are generally closer for audio than for lighting systems, indicating that day and night baseloads are closer in audio systems than in lighting systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α17	Base Day-Band	0.67	0.92	0.39	0.03	0.99	7
α18	Base Day-CO	0.81	0.80	0.28	0.42	1.23	7
α19	Base Fri-Sun-Day	1.08	1.00	0.56	0.39	2.22	7
α20	Base Fri-Sun-Night	1.03	1.01	0.04	1.00	1.11	7

Table 40- Summary of audio baseload uniformity coefficients

	α17	α18	α19	α20
	Base Day-Band	Base Day-CO	Base Fri-Sun-Day	Base Fri-Sun-Night
B2	0.24	0.55	2.22	1.01
D3	0.94	0.94	1.00	1.01
F1	0.99	0.80	0.95	1.01
H1	0.67	1.23	1.20	1.03
N6	0.94	0.42	0.39	1.11
Q7	0.92	0.75	0.79	1.02
Q8	0.03	1.00	1.00	1.00

Table 41 - Stage audio BUC values

Many of the audio systems and video systems display a similar baseload between day and night periods, as shown by the similarity in α_{19} and α_{20} in these systems. This trend indicates that these systems are either operating efficiently during the day with equipment deactivated as much as possible, or are operating inefficiently at night, with equipment left 'dimmed', but still active. Given the spikes in consumption overnight, and the increased demand in system F3 overnight, it is likely that these systems are being left on standby.

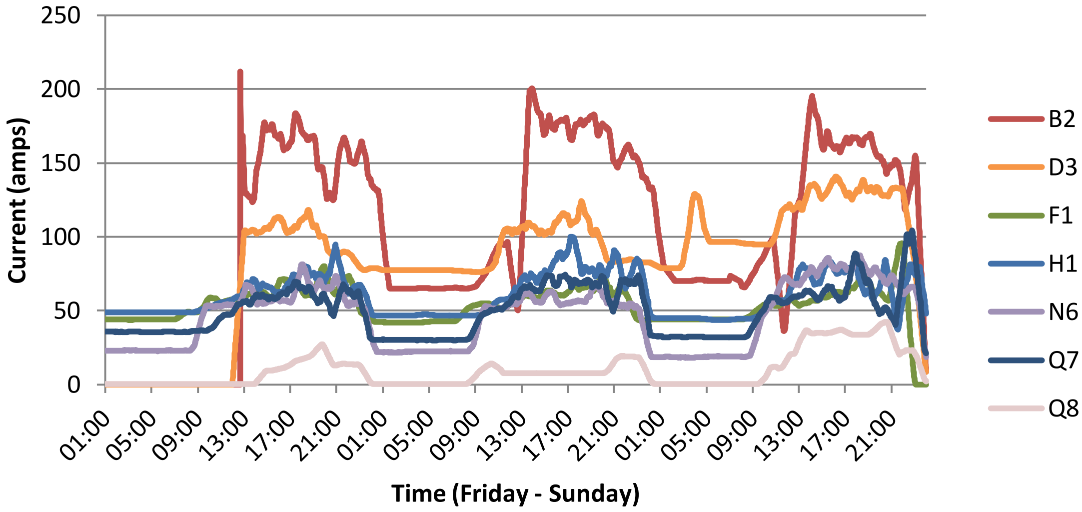


Figure 33 - 60 minute rolling average audio load profiles

Table 42 contains the summary statistics of the impact factors (IF). Table 43 presents the full results for impact factors for all audio systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α21	Impact Night/Day	0.50	0.49	0.28	0.01	0.85	7
α22	Impact Band/Day	1.06	1.06	0.04	1.00	1.10	7
α23	Impact CO/Day	0.93	0.91	0.19	0.67	1.19	7
α24	Impact CO/Band	0.88	0.86	0.21	0.61	1.18	7
α25	Impact Day/Fri/Sun	1.22	1.20	0.14	1.07	1.50	7
α26	Impact Night/Fri/Sun	0.57	0.59	0.29	0.02	0.91	7

Table 42 - Summary of stage audio impact factors

All factors other than α_{21} are consistent (discounting Q8), showing similar patterns to those which can be seen in the load profile diagrams, as well as the trends that are seen in lighting demand with regard to the difference in performance between day and night, and between bands and changeover periods.

	α21 Impact Night/Day	α22 Impact Band/Day	α23 Impact CO/Day	α24 Impact CO/Band	α25 Impact Day/Fri/Sun	α26 Impact Night/Fri/Sun
B2	0.44	1.01	1.19	1.18	1.23	0.55
D3	0.85	1.04	1.05	1.01	1.07	0.91
F1	0.72	1.00	1.06	1.07	1.11	0.79
H1	0.64	1.10	0.84	0.76	1.15	0.73
N6	0.32	1.06	0.91	0.86	1.29	0.42
Q7	0.49	1.10	0.76	0.69	1.20	0.59
Q8	0.01	1.09	0.67	0.61	1.50	0.02

Table 43 - Stage audio IF values

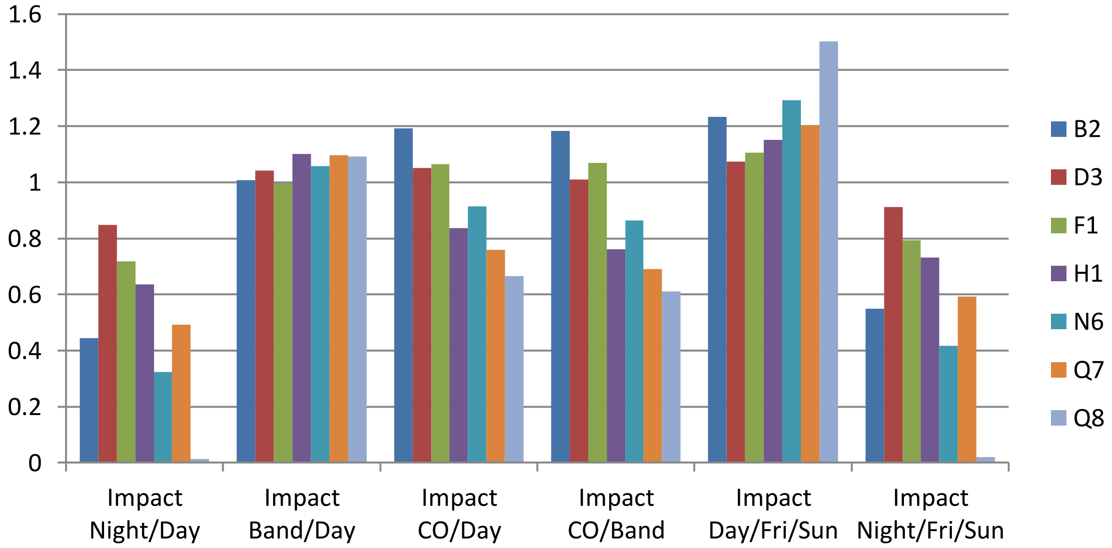


Figure 34 - Impact factor values for audio systems

6.3 Stage video systems

Load factor

Table 44 contains the summary statistics of the load factor profile results. Table 45 presents the full results for impact factors for all video systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α1	LF Day	0.50	0.47	0.14	0.32	0.67	7
α2	LF Night	0.75	0.83	0.21	0.49	1.00	7
α3	LF Band	0.52	0.56	0.14	0.30	0.69	7
α4	LF CO	0.63	0.65	0.11	0.46	0.78	7
α5	LF Overall	0.44	0.44	0.14	0.24	0.61	7

Table 44 - Summary of stage video load factors

Load factor performance in video systems is comparable to that in the audio systems. These systems are often combined (systems D3, Q6 and Q8 all share responsibility for these systems), meaning that this overlap should be expected. Night load factor is has 50% greater standard deviation than any other time period. This is due to singular increases in demand during the night in systems D3 and H5, and a different overnight load on each night in system B3, though both nights exhibit almost constant demand.

	α1	α2	α3	α4	α5
	LF Day	LF Night	LF Band	LF CO	LF Overall
B3	0.67	0.61	0.69	0.73	0.47
D3	0.47	0.49	0.56	0.54	0.44
F3	0.61	0.84	0.63	0.65	0.61
H5	0.47	0.51	0.48	0.57	0.44
N7	0.32	0.83	0.30	0.70	0.28
Q6	0.64	0.96	0.61	0.78	0.57
Q8	0.36	1.00	0.39	0.46	0.24

Table 45 - Stage video load factor values

Modulation factor

Table 46 contains the summary statistics of the modulation factor profile results. Table 47 presents the full results for modulation factor indicators for all video systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α6	Mod Day	0.54	0.60	0.27	0.01	0.81	7
α7	Mod Night	0.80	0.86	0.23	0.31	1.00	7
α8	Mod Band	0.74	0.76	0.18	0.39	0.94	7
α9	Mod CO	0.60	0.69	0.28	0.02	0.90	7
α10	Mod Overall	0.55	0.71	0.34	0.02	0.79	7

Table 46 - Summary of stage video modulation factors

	α6	α7	α8	α9	α10
System	Mod Day	Mod Night	Mod Band	Mod CO	Mod Overall
B3	0.37	0.31	0.94	0.90	0.08
D3	0.74	0.86	0.76	0.74	0.79
F3	0.66	0.86	0.80	0.69	0.73
H5	0.60	0.75	0.67	0.51	0.71
N7	0.59	0.87	0.76	0.64	0.71
Q6	0.81	0.96	0.88	0.71	0.79
Q8	0.01	1.00	0.39	0.02	0.02

Table 47 - Stage video modulation factor values

Excluding Q8, all systems produce similar values for all MF values other than B3. B3 performs differently to all other video systems over the course of the weekend. The difference in overnight demand has already been mentioned, but all other systems noticeably vary throughout the weekend, from a baseload level up to another level, with a separate level of consumption at night. In comparison, B3 has very little variation, maintaining a consumption of between 120 and 135 amps during daytime periods, with markedly different night baseloads. The consistency in results for generic video systems since 2010 however should be highlighted as encouraging for standardisation, but a larger dataset would be beneficial, as with the audio systems. The sampling issues found with minimum values in lighting were not found to be an issue with video, due to the consistent demand in the video systems.

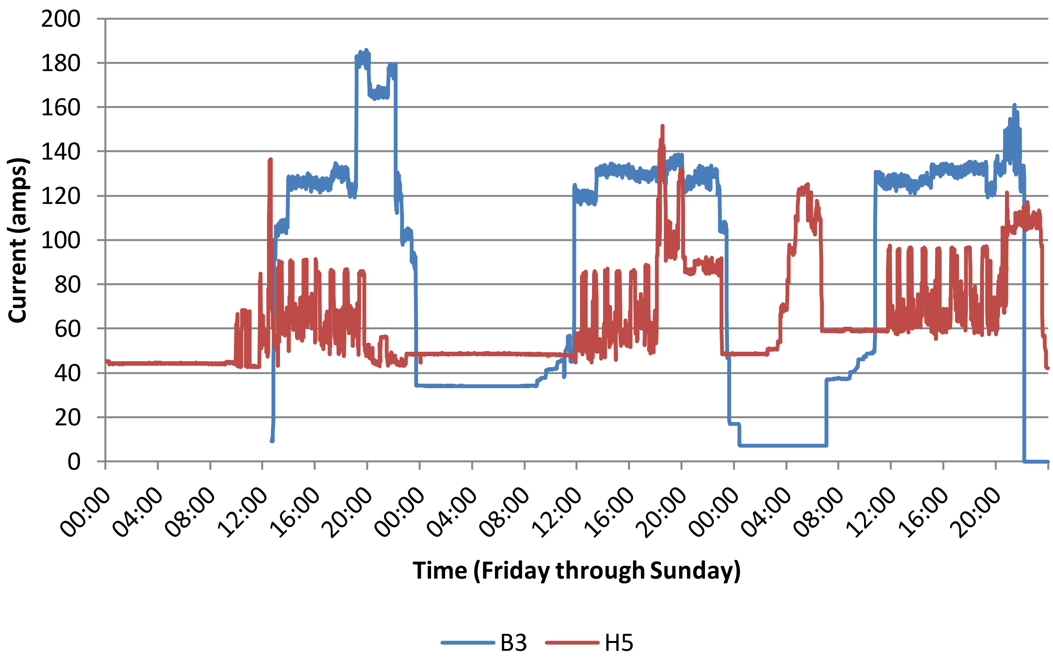


Figure 35 - Comparison between two video system load profiles

Cross period analysis (PDUC, BUC, IF)

Table 48 contains the summary statistics of the peak demand uniformity coefficient. Table 49 presents the full results for PDUC indicators for all video systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α11	Peak band-day	0.96	0.98	0.05	0.88	1.00	7
α12	Peak CO-day	0.84	0.93	0.22	0.51	1.00	7
α13	Peak band-Fri/Sun	0.96	0.96	0.05	0.88	1.00	7
α14	Peak CO Fri/Sun	0.84	0.93	0.22	0.51	1.00	7
α15	Peak Day-Fri/Sun	1.00	1.00	0.01	0.98	1.00	7
α16	Peak Night-Fri/Sun	0.47	0.47	0.32	0.00	0.83	7

Table 48 - Summary of stage video peak demand uniformity coefficients

	α11 Peak band-day	α12 Peak CO-day	α13 Peak band-Fri/Sun	α14 Peak CO Fri/Sun	α15 Peak Day-Fri/Sun	α16 Peak Night-Fri/Sun
B3	1.00	1.00	1.00	1.00	1.00	0.20
D3	0.88	0.93	0.88	0.93	1.00	0.81
F3	0.91	1.00	0.91	1.00	1.00	0.69
H5	0.95	1.00	0.95	1.00	1.00	0.83
N7	1.00	0.52	1.00	0.52	1.00	0.26
Q6	0.98	0.92	0.96	0.91	0.98	0.47
Q8	1.00	0.51	1.00	0.51	1.00	0.00

Table 49 - Stage video PDUC values

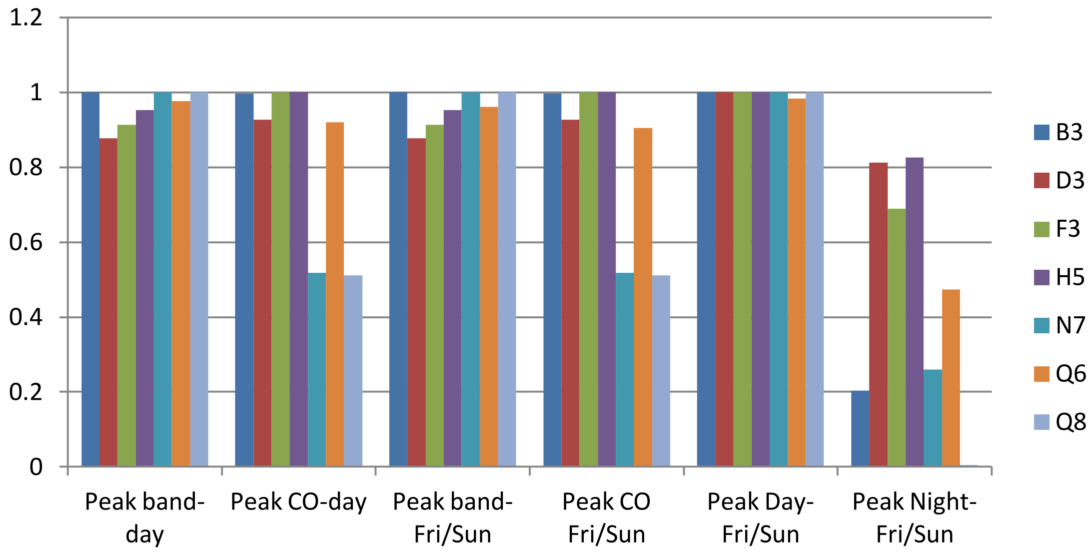


Figure 36 - PDUC values for video systems

Daytime video PDUC values align closely with the values already seen in audio and lighting, with peaks aligning with band performances, but with some reductions during changeover periods. Factor α_{15} however has values evenly dispersed from 0 to 0.83, indicating there is no trend in the data.

All but three results for video BUC are within the range of 0.83 and 1.11, again highlighting that there is little difference between the baseload demands of festival video systems, regardless of the timeframe. The large standard deviation values are caused single results in systems B3 and Q8. Both of these systems have previously been described, and their results should not detract from the similarities shown throughout the rest of the group.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α17	Base Day-Band	0.71	0.87	0.36	0.03	0.98	7
α18	Base Day-CO	0.83	0.94	0.35	0.06	1.06	7
α19	Base Fri-Sun-Day	0.90	1.00	0.34	0.16	1.11	7
α20	Base Fri-Sun-Night	1.00	1.00	0.06	0.88	1.07	7

Table 50 - Summary of stage video baseload uniformity coefficients

	α17	α18	α19	α20
System	Base Day-Band	Base Day-CO	Base Fri-Sun-Day	Base Fri-Sun-Night
B3	0.38	0.06	0.16	1.00
D3	0.94	0.94	1.00	1.01
F3	0.87	1.00	1.11	0.88
H5	0.93	1.06	1.09	0.98
N7	0.83	0.87	1.08	1.07
Q6	0.98	0.90	0.89	1.03
Q8	0.03	1.00	1.00	1.00

Table 51 - Stage video BUC values

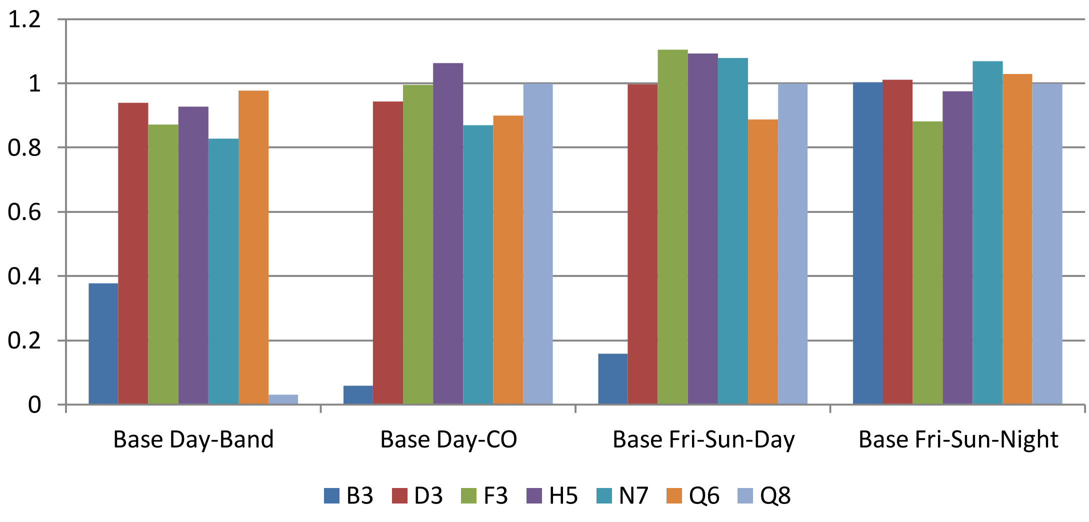


Figure 37 - BUC values for video systems

Table 52 contains the summary statistics of the impact factors. Table 53 presents the full results for impact factors for all video systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α21	Impact Night/Day	0.62	0.73	0.37	0.01	0.96	7
α22	Impact Band/Day	0.99	0.97	0.06	0.93	1.09	7
α23	Impact CO/Day	1.05	1.08	0.18	0.67	1.21	7
α24	Impact CO/Band	1.07	1.13	0.22	0.61	1.25	7
α25	Impact Day/Fri/Sun	1.19	1.10	0.19	1.00	1.50	7
α26	Impact Night/Fri/Sun	0.67	0.80	0.37	0.02	0.97	7

Table 52 - Summary of stage video demand impact factors

	α21	α22	α23	α24	α25	α26
System	Impact Night/Day	Impact Band/Day	Impact CO/Day	Impact CO/Band	Impact Day/Fri/Sun	Impact Night/Fri/Sun
B3	0.18	1.03	1.08	1.05	1.42	0.26
D3	0.85	1.04	1.05	1.01	1.07	0.91
F3	0.96	0.94	1.07	1.13	1.00	0.96
H5	0.90	0.97	1.21	1.25	1.08	0.97
N7	0.68	0.93	1.14	1.23	1.12	0.76
Q6	0.73	0.94	1.13	1.20	1.10	0.80
Q8	0.01	1.09	0.67	0.61	1.50	0.02

Table 53 - Stage video impact factor values

B3 and Q8 again yield results different to the rest of the group. The other 5 systems all provide IF values within a range of 0.3 for each IF. Discounting these results, video demand is further shown to be a consistent demand throughout the festival, with little variation in average demand. This notion however does not conform to the higher resolution, minute by minute data shown in figure 35 . The fact that the average values suggest there is consistency between these periods is a limitation to using an analysis based on using average demand when demand can be seen to be variable between a series of levels.

Changeover periods in video systems draw more power on average than during artist performances. This result does not sit with the expectation that demand would decrease when artists aren't on stage. Video screens are typically used during performances to broadcast live footage to the audience, and used for advertising between these performances. The load profiles themselves show that this pattern is similar to that seen in audio demand in figure 38, suggesting that the circuit may have been incorrectly labelled, with system B2 potentially providing power for video rather than audio.

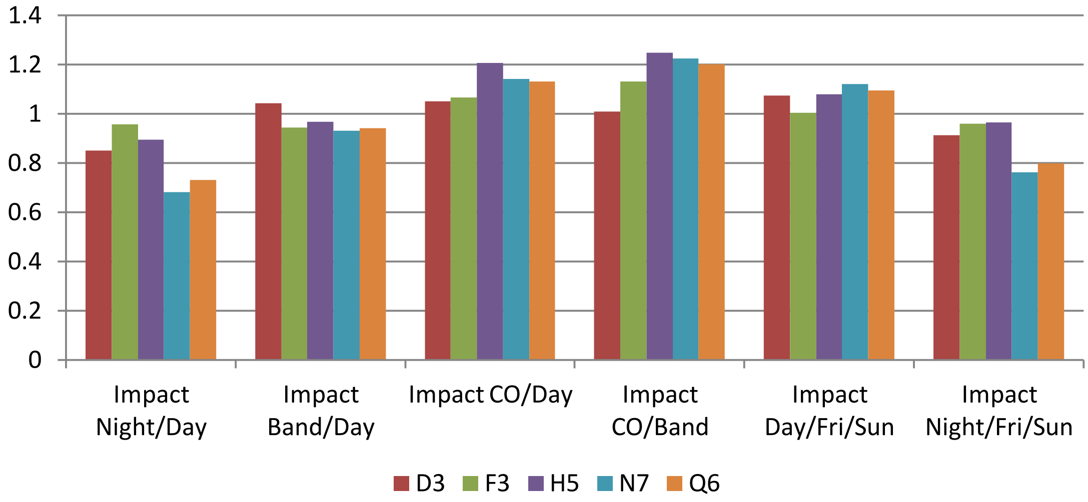


Figure 38 - Impact factor values for video systems (B3 and Q8 omitted)

6.4 Stages

This section considers stages as a whole, rather than breaking it down between the separate systems as has been done in the previous sections. The behaviour of a stage as a whole is what will commonly need to be considered in practical terms, as it is the stage as a whole that will be provided a generator in most situations, and not the individual systems. Some of these are composite datasets compiled from subsystems used in the analysis of lighting, audio and video systems previously, however this is only done in systems where every subsystem has been recorded.

Load factor

Table 54 contains the summary statistics of the load factors. Table 55 presents the full results for load factors for all stages.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α1	LF Day	0.51	0.53	0.10	0.35	0.62	12
α2	LF Night	0.67	0.65	0.20	0.31	0.97	12
α3	LF Band	0.55	0.56	0.08	0.38	0.64	12
α4	LF CO	0.59	0.61	0.11	0.38	0.77	12
α5	LF Overall	0.42	0.43	0.08	0.25	0.52	12

Table 54 - Summary of stage load factors

	α1	α2	α3	α4	α5
System	LF Day	LF Night	LF Band	LF CO	LF Overall
E5	0.42	0.95	0.60	0.56	0.39
G2	0.61	0.50	0.56	0.66	0.44
G5	0.59	0.62	0.64	0.62	0.52
K2	0.58	0.88	0.63	0.70	0.48
K4	0.53	0.66	0.57	0.60	0.43
M1	0.52	0.41	0.50	0.46	0.45
N2	0.35	0.59	0.38	0.59	0.29
Sum N4-N8	0.48	0.65	0.50	0.67	0.43
O1 + O2	0.46	0.72	0.48	0.45	0.42
O3	0.62	0.31	0.61	0.61	0.52
P2	0.35	0.97	0.46	0.38	0.25
Sum Q1-Q8	0.59	0.73	0.63	0.77	0.46

Table 55 - Stage load factor values

Stages conform to the trends shown in their subsystems with a band of load factors evident between 0.4 and 0.6 for stages at individual time periods, although this lowers to 0.3 and 0.5 for α_5 over the entire weekend. Night load factor α_2 is unexpectedly low, as many of these stages have consistent demand overnight when viewed with visual analysis. This is due to either deactivation of the stage equipment occurring after 02:00, or early morning activation processes occurring in before 08:00, or late night activities taking place on the stages. These sampling contaminations occurred only on some of the non-main stages at medium festivals of less than 15,000 people. These are the middle of the range stages examined, with all stages larger than these accounting for main stages, and all stages smaller than these accounting for secondary or tertiary stages at small or medium events where the stage is not the sole responsibility of its generator, as some of these stages share power with nearby traders or bars, some of which are located within the tented area of the stage.

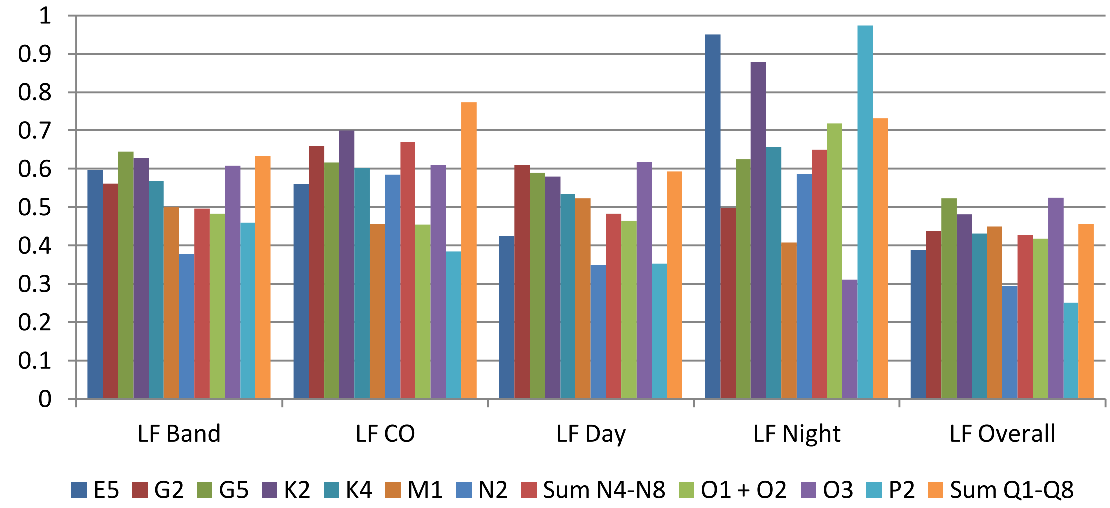


Figure 39 - Load factor values for stages

Modulation factor

Table 56 contains the summary statistics of the modulation factor profile results. Table 57 presents the full results for modulation factor indicators for all stages.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α6	Mod Day	0.60	0.68	0.19	0.17	0.79	12
α7	Mod Night	0.67	0.75	0.27	0.00	0.91	12
α8	Mod Band	0.70	0.73	0.12	0.48	0.87	12
α9	Mod CO	0.70	0.70	0.10	0.50	0.85	12
α10	Mod Overall	0.44	0.43	0.16	0.21	0.75	12

Table 56 - Summary of stage modulation factors

Each time subsection has consistent results, but as with many of the systems analysed through modulation factor, there are some inconsistencies. Most of the MF values fall between 0.6 and 0.8 during the time subsections, although α_{10} has a more diverse, but evenly spread range, meaning that there is not any value that should be expected for future system analysis. Given the consistency of the smaller timeframes however, this indicates that consumption patterns in these timeframes can be predicted, but the scale of the difference between time periods, day and night in particular, is variable. Despite the variety of stages analysed in this section, representing a variety of sizes and purposes, there is no correlation between these stage types and the modulation factor results.

	α6	α7	α8	α9	α10
System	Mod Day	Mod Night	Mod Band	Mod CO	Mod Overall
E5	0.54	0.89	0.64	0.61	0.75
G2	0.64	0.00	0.70	0.70	0.24
G5	0.70	0.70	0.71	0.69	0.55
K2	0.66	0.89	0.79	0.74	0.46
K4	0.73	0.75	0.80	0.77	0.41
M1	0.25	0.29	0.63	0.63	0.26
N2	0.71	0.83	0.74	0.73	0.51
Sum N4-N8	0.79	0.76	0.87	0.84	0.58
O1 + O2	0.69	0.69	0.74	0.70	0.57
O3	0.67	0.59	0.49	0.50	0.36
P2	0.17	0.74	0.48	0.59	0.21
Sum Q1-Q8	0.69	0.91	0.78	0.85	0.33

Table 57 - Stage modulation factor values

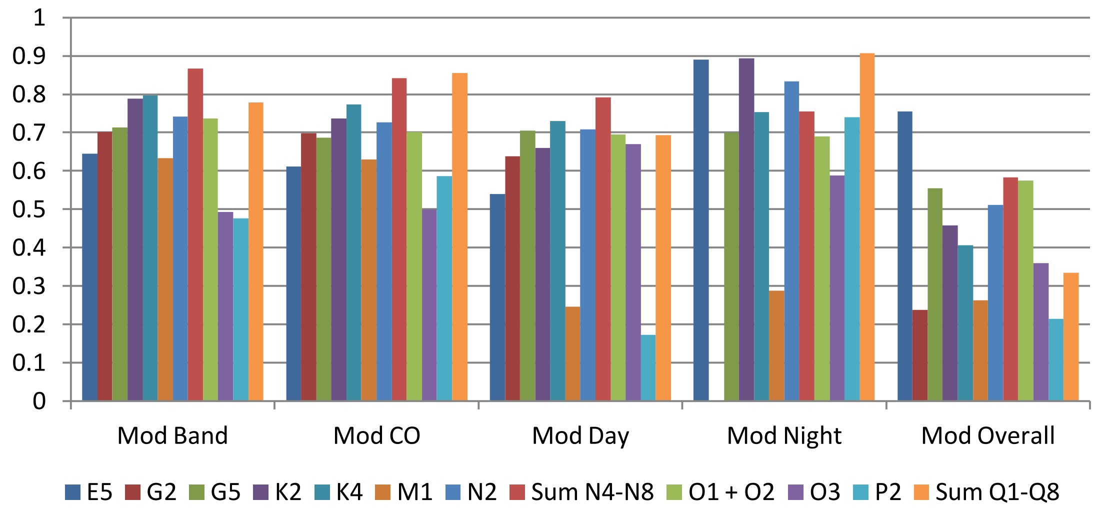


Figure 40 - Modulation factor values for stages

Cross period analysis (PDUC, BUC, IF)

Table 58 contains the summary statistics of the peak demand uniformity coefficient. Table 59 presents the full results for PDUC indicators for all stages.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α11	Peak band-day	1.01	1.00	0.04	0.96	1.10	12
α12	Peak CO-day	0.84	0.85	0.14	0.57	1.00	12
α13	Peak band-Fri/Sun	1.00	1.00	0.03	0.96	1.10	12
α14	Peak CO Fri/Sun	0.83	0.85	0.13	0.57	1.00	12
α15	Peak Day-Fri/Sun	0.99	1.00	0.02	0.92	1.00	12
α16	Peak Night-Fri/Sun	0.42	0.34	0.29	0.08	1.00	12

Table 58 - Summary of stage peak demand uniformity coefficients

System	α11 Peak band-day	α12 Peak CO-day	α13 Peak band-Fri/Sun	α14 Peak CO Fri/Sun	α15 Peak Day-Fri/Sun	α16 Peak Night-Fri/Sun
E5	1.00	0.91	0.98	0.89	0.98	0.36
G2	1.10	0.83	1.10	0.83	1.00	0.10
G5	1.00	1.00	1.00	1.00	1.00	0.57
K2	0.96	0.87	0.96	0.87	1.00	0.26
K4	1.00	0.82	1.00	0.82	1.00	0.31
M1	1.09	1.00	1.00	0.92	0.92	1.00
N2	1.00	0.57	1.00	0.57	1.00	0.29
Sum N4-N8	1.00	0.70	1.00	0.70	1.00	0.47
O1 + O2	1.00	0.98	1.00	0.98	1.00	0.45
O3	1.00	0.97	1.00	0.97	1.00	0.92
P2	1.00	0.78	1.00	0.78	1.00	0.08
Sum Q1-Q8	1.00	0.66	1.00	0.66	1.00	0.22

Table 59 - Stage PDUC values

Stage PDUC performance aligns closely with those found in the lighting, audio and video subsystems. The only variation here is the presence of values greater than 1. This is due peak band demand occurring outside of the standard daytime period, as the artist schedule continued beyond the regular 11pm cut-off.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α17	Base Day-Band	0.80	0.87	0.28	0.28	1.38	12
α18	Base Day-CO	0.55	0.56	0.20	0.27	0.96	12
α19	Base Fri-Sun-Day	0.67	0.63	0.29	0.27	1.30	12
α20	Base Fri-Sun-Night	0.97	1.05	0.31	0.00	1.15	12

Table 60 - Summary of stage baseload uniformity coefficients

System	α17 Base Day-Band	α18 Base Day-CO	α19 Base Fri-Sun-Day	α20 Base Fri-Sun-Night
E5	0.60	0.96	1.30	0.95
G2	0.90	0.27	0.27	0.00
G5	0.91	0.69	0.70	1.15
K2	0.80	0.49	0.58	1.07
K4	0.86	0.46	0.45	1.13
M1	0.37	0.45	1.00	1.01
N2	0.88	0.62	0.61	1.04
Sum N4-N8	0.89	0.63	0.65	1.08
O1 + O2	0.91	0.77	0.74	1.07
O3	1.38	0.64	0.46	1.12
P2	0.28	0.31	0.89	0.93
Sum Q1-Q8	0.84	0.35	0.37	1.03

Table 61 - Stage BUC values

Baseload uniformity coefficients are subject to variation throughout the dataset. This aligns with the diverse results found in α_{10}, as each stage exhibits different balances between separate timeframes, yet is consistent during each one. Night baseload is consistently identified as the lowest level of demand throughout the festival weekend.

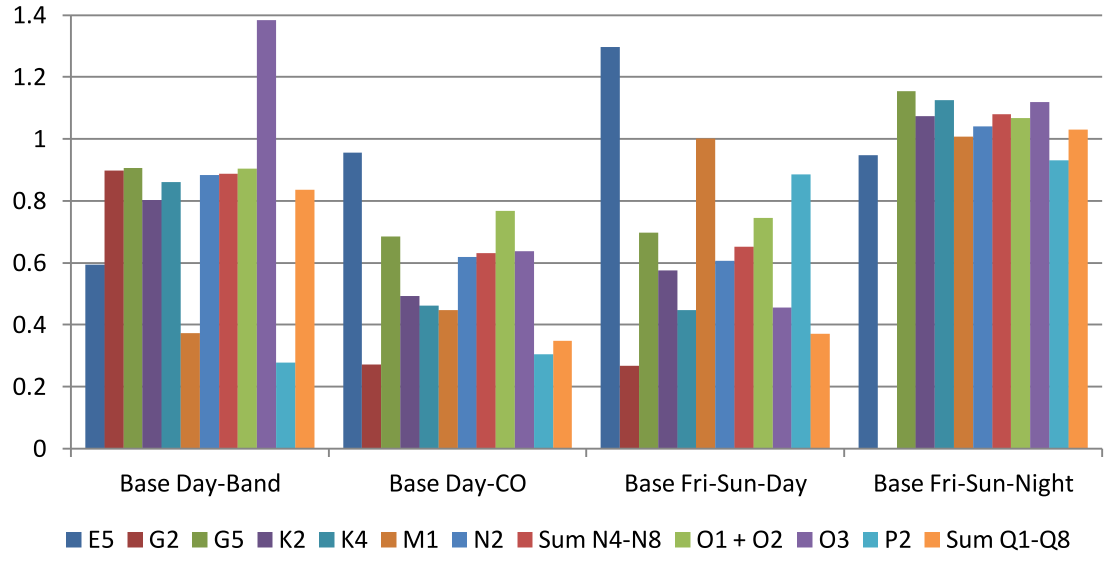


Figure 41 - Baseload uniformity coefficient values for stages

Table 62 contains the summary statistics of the impact factors. Table 63 presents the full results for impact factors for all stages.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α21	Impact Night/Day	0.50	0.48	0.24	0.09	0.85	12
α22	Impact Band/Day	1.10	1.05	0.13	0.98	1.40	12
α23	Impact CO/Day	0.96	0.96	0.10	0.85	1.20	12
α24	Impact CO/Band	0.88	0.88	0.09	0.65	1.00	12
α25	Impact Day/Fri/Sun	1.20	1.18	0.11	1.07	1.40	12
α26	Impact Night/Fri/Sun	0.57	0.57	0.24	0.12	0.91	12

Table 62 - Summary of stage impact factors

	α21	α22	α23	α24	α25	α26
System	Impact Night/Day	Impact Band/Day	Impact CO/Day	Impact CO/Band	Impact Day/Fri/Sun	Impact Night/Fri/Sun
E5	0.83	1.40	1.20	0.85	1.08	0.89
G2	0.09	1.01	0.90	0.89	1.39	0.12
G5	0.61	1.09	1.05	0.96	1.13	0.69
K2	0.40	1.04	1.04	1.00	1.21	0.48
K4	0.39	1.06	0.92	0.86	1.24	0.48
M1	0.85	1.04	0.87	0.84	1.07	0.91
N2	0.50	1.08	0.95	0.88	1.19	0.59
Sum N4-N8	0.63	1.03	0.97	0.94	1.13	0.71
O1 + O2	0.70	1.04	0.96	0.92	1.11	0.78
O3	0.46	0.98	0.96	0.97	1.18	0.55
P2	0.22	1.30	0.85	0.65	1.40	0.31
Sum Q1-Q8	0.28	1.07	0.87	0.81	1.30	0.36

Table 63 - Stage impact factor values

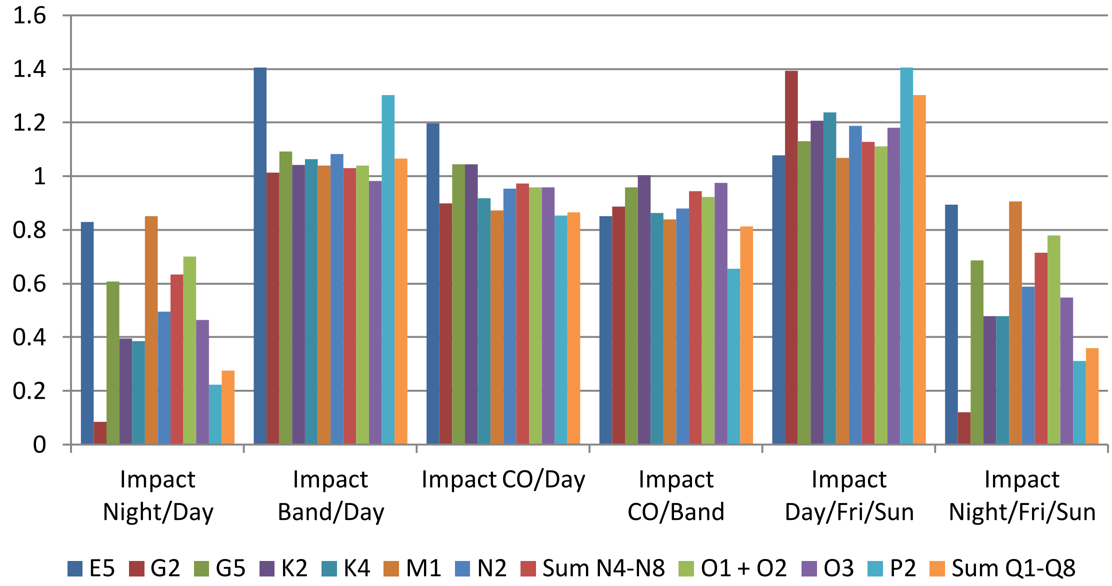


Figure 42 - Impact factor values for stages

The impact factors for stages exhibit the same trends as shown by lighting and audio, with greater demand during artist performances, and less during changeover periods, and at night, although the magnitude of this trend is reduced by the load profile shown by video systems. The lack of consistent values for overall weekend performance again is an issue, however the decreased demands of the night period are again highlighted.

6.5 Traders

This section examines the performance of traders at festivals. The systems analysed represent groups of traders, not just singular traders. Each of these systems served over 10 individual traders offering a variety of services, though the primary purpose of the majority of these was to serve hot food.

Band and changeover analyses have not been carried out on the majority of trader systems, as these schedules are not directly relevant. System R1 was subjected to band and changeover analysis, as R1 was used to provide power to a small stage as well as traders. The overall behaviour of R1 conformed to the model seen with traders, with no reaction to the artist schedule. R1's most significant event was two consecutive power cuts, each lasting approximately 2 hours. Demand after these power cuts aligns with the expected load profile.

Load factor

Table 64 contains the summary statistics of the load factors. Table 65 presents the full results for load factors for all trader systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α1	LF Day	0.66	0.67	0.11	0.47	0.79	8
α2	LF Night	0.63	0.69	0.12	0.39	0.73	8
α5	LF Overall	0.57	0.57	0.11	0.38	0.70	8

Table 64 - Summary of trader load factors

	α1	α2	α5
System	LF Day	LF Night	LF Overall
E2	0.47	0.73	0.38
I1	0.79	0.69	0.64
K3	0.71	0.61	0.57
M2	0.75	0.71	0.68
M3	0.77	0.70	0.70
O6	0.60	0.39	0.49
P3	0.63	0.69	0.52
R1	0.58	0.54	0.56

Table 65 - Trader load factor values

The consistency of these load factors mirrors the consistency of the load profiles for traders. The performance issues with E2 and R1 outlined previously explain the low α_1 and α_5 values returned in these systems, and the low α_5 for O6 is due to the later opening hours allowed to traders at festival O. Visually, these systems can be clearly seen to have a diurnal function that will be caused by the presence of the audience. R1 also had later opening hours, and as a result had a longer 'day' period.

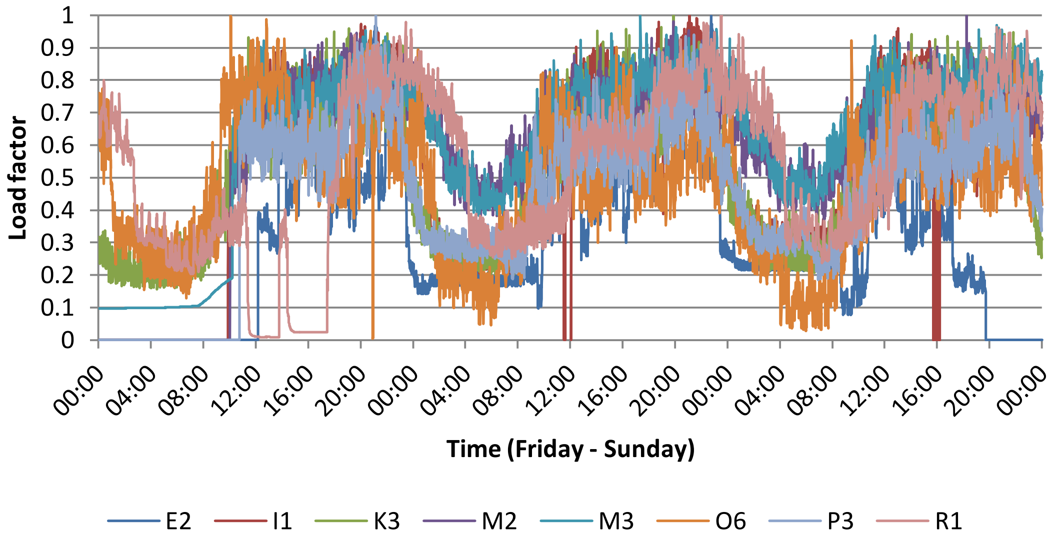


Figure 43 - Load factor profiles for traders

Modulation factor

Table 66 contains the summary statistics of the modulation factor profile results. Table 67 presents the full results for modulation factor indicators for all traders.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α6	Mod Day	0.67	0.75	0.18	0.34	0.83	8
α7	Mod Night	0.64	0.71	0.21	0.16	0.82	8
α10	Mod Overall	0.46	0.43	0.14	0.25	0.67	8

Table 66 - Summary of trader modulation factors

System	α6 Mod Day	α7 Mod Night	α10 Mod Overall
E2	0.34	0.82	0.43
I1	0.80	0.72	0.39
K3	0.79	0.76	0.40
M2	0.74	0.70	0.67
M3	0.83	0.77	0.64
O6	0.68	0.16	0.25
P3	0.75	0.65	0.49
R1	0.44	0.52	0.43

Table 67 - Trader modulation factor values

Modulation factor has a wider dispersion of results than load factor, however this is due to low values in systems E2 (α_6) and O6 (α_7 and α_{10}). System E2 has a lowα_6 value due to festival E finishing early on the Sunday, and therefore reducing demand on the traders during what is typically the daytime period. System O6 however has much lower minimums overnight than other trader systems, thereby reducing α_7 and α_{10}. All systems other than O6 draw much larger current, which implies that there may be a difference between the load profiles of large trading rings and small ones.

Trader	Daytime average demand (amps)
E2	132
I1	282
K3	187
M2	358
M3	227
O6	45
P3	175
R1	331

Table 68 - Average daytime demand for each trader system

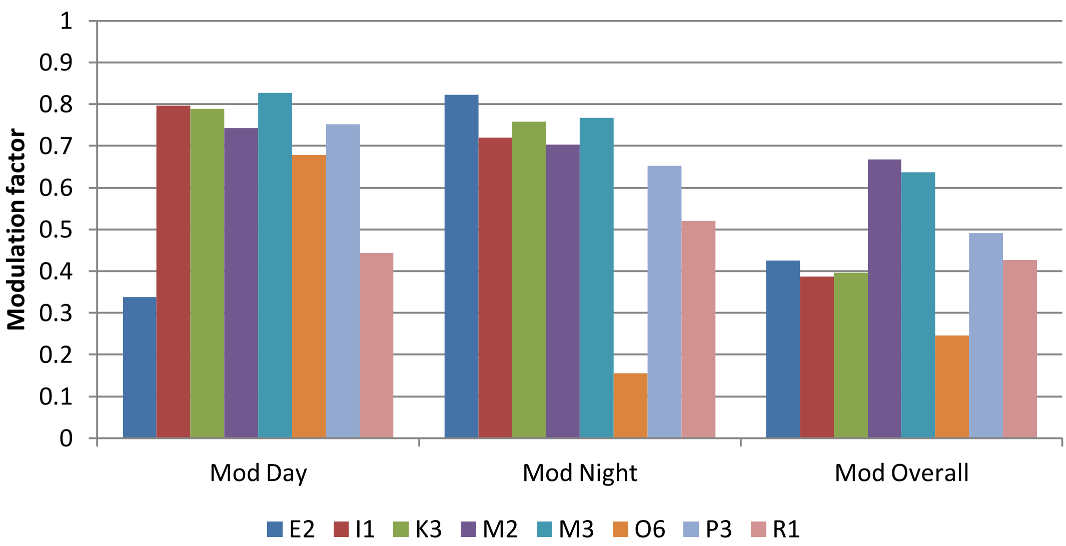


Figure 44 - Modulation factor values for traders

Cross period analysis (PDUC, BUC, IF)

Table 69 contains the summary statistics of the peak demand uniformity coefficient. Table 70 presents the full results for PDUC indicators for all traders.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α15	Peak Day-Fri/Sun	1.00	1.00	0.00	1.00	1.00	8
α16	Peak Night-Fri/Sun	0.53	0.45	0.20	0.27	0.84	8

Table 69 - Summary of trader peak demand uniformity coefficients

	α15	α16
System	Peak Day-Fri/Sun	Peak Night-Fri/Sun
E2	1.00	0.27
I1	1.00	0.41
K3	1.00	0.42
M2	1.00	0.71
M3	1.00	0.71
O6	1.00	0.48
P3	1.00	0.41
R1	1.00	0.84

Table 70 - Trader PDUC values

As shown in figure 43, peak demand occurs during the day, with night demand reduced. Systems M2, M3 and all have elevated α_{16} values in comparison to the other trader systems, and are due to longer operating hours used for these traders.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α19	Base Fri-Sun-Day	0.64	0.62	0.27	0.30	1.01	8
α20	Base Fri-Sun-Night	1.55	1.19	1.09	0.98	4.22	8

Table 71 - Summary of trader baseload uniformity coefficients

System	α19 Base Fri-Sun-Day	α20 Base Fri-Sun-Night
E2	1.01	0.98
I1	0.39	1.21
K3	0.40	1.16
M2	0.82	1.28
M3	0.70	1.17
O6	0.30	4.22
P3	0.54	1.37
R1	0.92	1.01

Table 72 - Trader BUC values

The converse of the PDUC factor, BUC shows that the lowest demands on a trader system occur at night, however the sampling techniques to remove erroneous baseloads are more problematic in traders than shown with stage systems. The sampling techniques were designed to identify real baseloads in systems such as guest lighting systems that draw zero, or negligible amps for the majority of the festival. The only time trader systems draw negligible current is during power failures, and while these periods still need to be discounted, the process identifying minimum demand for traders may need to be different to the process for stages to take account of these different operating profiles.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α21	Impact Night/Day	0.50	0.44	0.17	0.31	0.78	8
α25	Impact Day/Fri/Sun	1.17	1.21	0.08	1.04	1.25	8
α26	Impact Night/Fri/Sun	0.58	0.54	0.16	0.37	0.81	8

Table 73 - Summary of trader impact factors

System	α21 Impact Night/Day	α25 Impact Day/Fri/Sun	α26 Impact Night/Fri/Sun
E2	0.42	1.25	0.53
I1	0.36	1.23	0.45
K3	0.36	1.25	0.45
M2	0.68	1.1	0.74
M3	0.64	1.1	0.71
O6	0.31	1.21	0.37
P3	0.46	1.21	0.55
R1	0.78	1.04	0.81

Table 74 - Trader impact factor values

The trends shown by all previous factors are shown by the impact factors, showing that average demand varies in the same way as peak and baseload demand. The presence of consistent results with all trader factors other than α_{19} and α_{20} allows for a simple model to be used for traders. For example that daytime average can be expected to be 25% greater than the weekend average, assuming that the results of M2, M3 and R1 are due to unique circumstances at that event. The disparity between these two subsets of data can only be resolved with a larger dataset.

6.6 Bars

Overall, bars exhibit the same trends as that found in the traders, which is expected as bars are large individual traders. As with traders, band and changeover analysis was not conducted with the majority of bar systems, however systems G5 and K4 both had a stage within the bar area. For these two systems, the artist schedule was noticeable in the load profiles, but only through using α_{24}.

System	α24 Impact CO/Band
G5	0.96
K4	0.86

Table 75 - Impact factor α_{24} for bars with small affiliated stages

Load factor

Table 76 contains the summary statistics of the load factors. Table 77 presents the full results for load factors for all trader systems.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α1	LF Day	0.58	0.58	0.11	0.42	0.72	8
α2	LF Night	0.65	0.64	0.16	0.41	0.95	8
α5	LF Overall	0.50	0.49	0.10	0.39	0.64	8

Table 76 - Summary of bar load factors

System	α1 LF Day	α2 LF Night	α5 LF Overall
E5	0.42	0.95	0.39
F5	0.64	0.59	0.56
G5	0.59	0.62	0.52
I2	0.72	0.75	0.62
K4	0.53	0.66	0.43
L1	0.57	0.51	0.45
N3	0.45	0.41	0.41
Q9	0.72	0.70	0.64

Table 77 - Bar load factor values

In all but E5, there is very little difference between factors α_1 and α_2. Other than this, there is little to conclude from these results, as while most results are returned as being in a range of approximately 0.4 to 0.75, the variability within this range means that nothing more can be concluded from the sample.

Modulation factor

Table 78 contains the summary statistics of the modulation factor profile results. Table 79 presents the full results for modulation factor indicators for all traders. As with load factor, discounting system E5, each system is notably consistent between both day and night periods.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α6	Mod Day	0.63	0.68	0.14	0.32	0.73	8
α7	Mod Night	0.64	0.70	0.19	0.28	0.89	8
α10	Mod Overall	0.53	0.56	0.13	0.36	0.75	8

Table 78 - Summary of bar load factors

System	α6 Mod Day	α7 Mod Night	α10 Mod Overall
E5	0.54	0.89	0.75
F5	0.69	0.70	0.60
G5	0.70	0.70	0.55
I2	0.67	0.76	0.57
K4	0.73	0.75	0.41
L1	0.64	0.58	0.38
N3	0.32	0.28	0.36
Q9	0.70	0.47	0.60

Table 79 - Bar modulation factor values

Cross period analysis (PDUC, BUC, IF)

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α15	Peak Day-Fri/Sun	1.00	1.00	0.01	0.98	1.00	8
α16	Peak Night-Fri/Sun	0.54	0.56	0.15	0.31	0.75	8

Table 80 - Summary of bar peak demand uniformity coefficients

	α15	α16
System	Peak Day-Fri/Sun	Peak Night-Fri/Sun
E5	0.98	0.36
F5	1.00	0.66
G5	1.00	0.57
I2	1.00	0.56
K4	1.00	0.31
L1	1.00	0.43
N3	1.00	0.75
Q9	1.00	0.65

Table 81 - Bar PDUC values

As with traders, peak demand occurs during the day, with reduced night demand that can be seen to vary. N3's high α_{16} value is due to a lowered daytime load rather than an increased night load, although this may simply indicate that night demand is inefficient rather than daytime demand being efficient.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α19	Base Fri-Sun-Day	0.77	0.74	0.28	0.45	1.30	8
α20	Base Fri-Sun-Night	1.30	1.19	0.30	0.95	1.77	8

Table 82 - Summary of bar baseload uniformity coefficients

	α19	α20
System	Base Fri-Sun-Day	Base Fri-Sun-Night
E5	1.30	0.95
F5	0.76	1.22
G5	0.70	1.15
I2	0.73	1.13
K4	0.45	1.13
L1	0.47	1.31
N3	1.00	1.72
Q9	0.75	1.77

Table 83 - Bar BUC values

Bar baseload is shown to occur at night although the sampling problems previously highlighted, particularly in traders, are again present.

Summary statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α21	Impact Night/Day	0.59	0.61	0.14	0.39	0.83	8
α25	Impact Day/Fri/Sun	1.16	1.14	0.06	1.08	1.26	8
α26	Impact Night/Fri/Sun	0.67	0.69	0.13	0.48	0.89	8

Table 84 - Summary of bar impact factors

	α21	α25	α26
System	Impact Night/Day	Impact Day/Fri/Sun	Impact Night/Fri/Sun
E5	0.83	1.08	0.89
F5	0.61	1.14	0.69
G5	0.61	1.13	0.69
I2	0.58	1.16	0.67
K4	0.39	1.24	0.48
L1	0.39	1.26	0.50
N3	0.67	1.12	0.75
Q9	0.63	1.13	0.72

Table 85 - Trader impact factor values

The diurnal split shown by PDUC and BUC is shown by impact factors, although only factor α_{25} displays reliably consistent results. As stated in previous sections, a larger dataset would allow for confirmation of these trends.

6.7 All other systems

The other systems monitored were ones that did not fit into the categories already used. These systems include tour buses, production offices, campsite lighting, campsite lighting combined with production offices, on site recycling plants, and power provided by the national grid in certain scenarios. A summary of the statistics from these systems is provided in tables 86 through 89. There are few conclusions to bring from the metrics for these systems due to the small number of individual samples for each system, and the variety of purposes they are used for.

Summary Statistics		Mean	Median	Standard Deviation	Minimum	Maximum	Count
α1	LF Day	0.57	0.64	0.24	0.21	0.88	12
α2	LF Night	0.62	0.71	0.20	0.23	0.90	12
α5	LF Overall	0.52	0.57	0.18	0.20	0.73	12
α6	Mod Day	0.58	0.60	0.23	0.02	0.84	12
α7	Mod Night	0.61	0.72	0.27	0.00	0.89	12
α10	Mod Overall	0.50	0.54	0.21	0.01	0.80	12
α15	Peak Day-Fri/Sun	0.99	1.00	0.03	0.92	1.00	12
α16	Peak Night-Fri/Sun	0.70	0.64	0.27	0.27	1.00	12
α19	Base Fri-Sun-Day	0.82	0.91	0.23	0.34	1.10	12
α20	Base Fri-Sun-Night	1.14	1.09	0.17	0.97	1.44	12
α21	Impact Night/Day	0.92	0.65	0.82	0.45	3.43	12
α25	Impact Day/Fri/Sun	1.07	1.12	0.18	0.56	1.23	12
α26	Impact Night/Fri/Sun	0.85	0.73	0.38	0.55	1.93	12

Table 86 - Summary of statistics for all other systems

	α1	α2	α5	α6	α7	α10
System	LF Day	LF Night	LF Overall	Mod Day	Mod Night	Mod Overall
A1	0.76	0.84	0.66	0.52	0.88	0.62
C1	0.88	0.76	0.73	0.84	0.73	0.54
E1	0.75	0.70	0.66	0.45	0.80	0.56
G1	0.78	0.90	0.70	0.76	0.70	0.59
I3	0.43	0.72	0.35	0.45	0.89	0.50
J1	0.65	0.56	0.61	0.68	0.62	0.68
J2	0.62	0.40	0.54	0.59	0.25	0.23
J3	0.21	0.23	0.20	0.83	0.78	0.80
K1	0.74	0.74	0.62	0.74	0.78	0.54
L2	0.26	0.36	0.22	0.49	0.56	0.45
O4	0.21	0.71	0.37	0.02	0.00	0.01
O5	0.51	0.57	0.52	0.61	0.36	0.54

Table 87 - Load factor and modulation factor values for all other systems

	α15	α16	α19	α20
System	Peak Day-Fri/Sun	Peak Night-Fri/Sun	Base Fri-Sun-Day	Base Fri-Sun-Night
A1	1.00	0.54	1.04	1.05
C1	1.00	0.58	0.53	1.21
E1	1.00	0.69	1.10	0.97
G1	1.00	0.60	0.69	1.08
I3	1.00	0.27	0.91	1.02
J1	0.98	1.00	0.96	1.19
J2	0.96	0.98	0.34	1.25
J3	0.92	0.94	1.01	0.97
K1	1.00	0.53	0.62	1.10
L2	1.00	0.33	0.76	1.44
O4	1.00	1.00	1.00	1.00
O5	1.00	0.95	0.91	1.44

Table 88 - PDUC and BUC values for all other systems

	α21	α25	α26
System	Impact Night/Day	Impact Day/Fri/Sun	Impact Night/Fri/Sun
A1	0.59	1.15	0.68
C1	0.50	1.20	0.60
E1	0.65	1.13	0.73
G1	0.69	1.12	0.77
I3	0.45	1.23	0.55
J1	0.88	1.04	0.91
J2	0.65	1.11	0.73
J3	1.12	0.95	1.06
K1	0.53	1.18	0.63
L2	0.46	1.19	0.55
O4	3.43	0.56	1.93
O5	1.08	0.97	1.05

Table 89 - Impact factor values for all other systems

This chapter has presented descriptive statistics for stages, traders and infrastructure systems at festivals. These can be used as the basis for modelling energy demand in systems. For discussion regarding the usefulness of the indicators, see section 6.10.

6.8 Percentile load analysis

So far this chapter has dealt with modelling energy performance in an effort to identify trends that can be used to monitor energy performance in future. This data can also be used to analyse how these systems are being used with regard to their generators. Generator oversizing has previously been mentioned as an issue regarding fuel wastage, and excessive GHG emissions. While the efficiency of a generator will be subject to many factors, the issue of capacity can be addressed solely through analysis of the current demand. In order to investigate this thoroughly, the size of each generator, and the total output of the generator must be recorded. For many of the systems monitored the size of the associated generator was either not available, or not relevant if the system monitored did not represent the total demand of the generator. As a result, comparison between the demand recorded and the potential capacity afforded to each system is not available for most of the data, although an analysis of those systems with generator sizes recorded is carried out in section 7.3.

In order to provide some insight into the sizing of generators beyond this limited sample, analysis of the load factor profiles have been used instead. As instantaneous load factor is a representation of demand at any moment against the maximum demand placed on the system, it allows for a similar comparison, working under the conservative estimate that maximum demand is equal to maximum potential supply. Figure 45 shows that the load distribution throughout the entire dataset is evenly spread across 95% of the festival weekend, with load factor not exceeding 72% during this time. The remaining 5% of the festival, equating to just less than 3 hours 40 minutes, is responsible for the final 28% of the load. These maximal loads can be seen at predictable periods in some systems, such as during headliner performance in lighting systems (both headliner and generic versions). Percentile profiles are another method of identifying levels of constant consumption, and each of the systems detailed in chapter 6 exhibit different profiles.

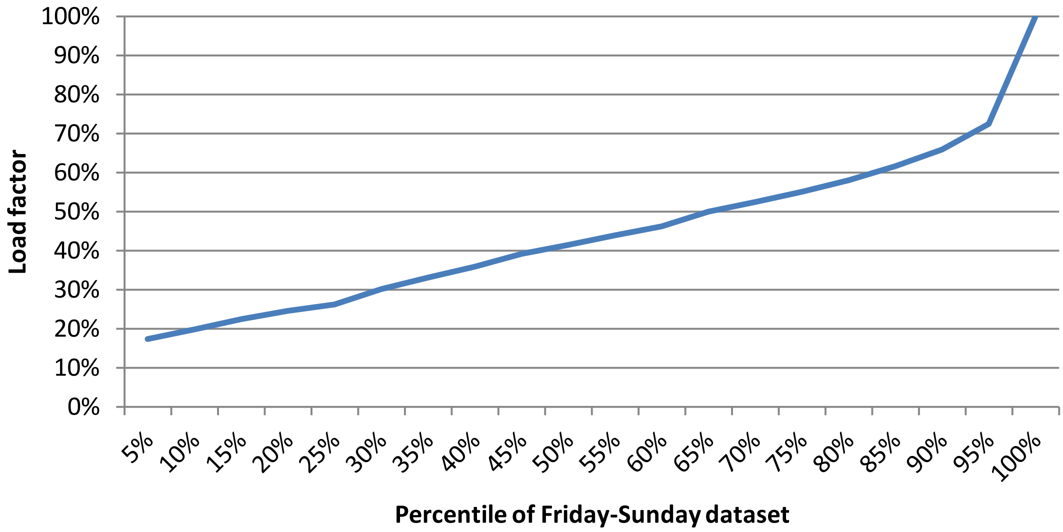


Figure 45 - Average load factor percentile profile, derived from all systems

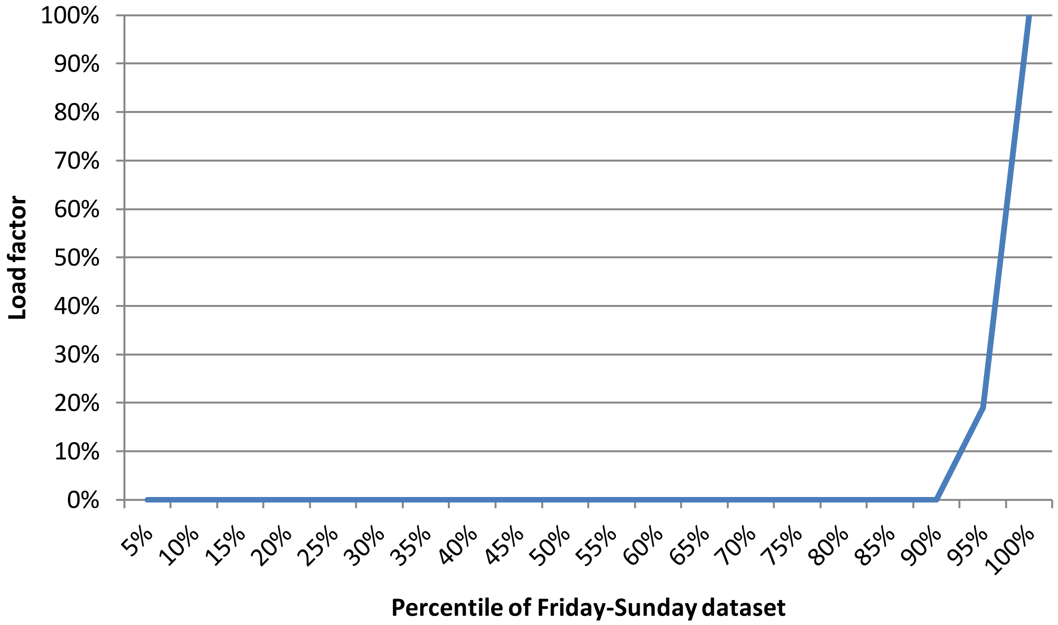


Figure 46 - Load factor percentile profile, system N5

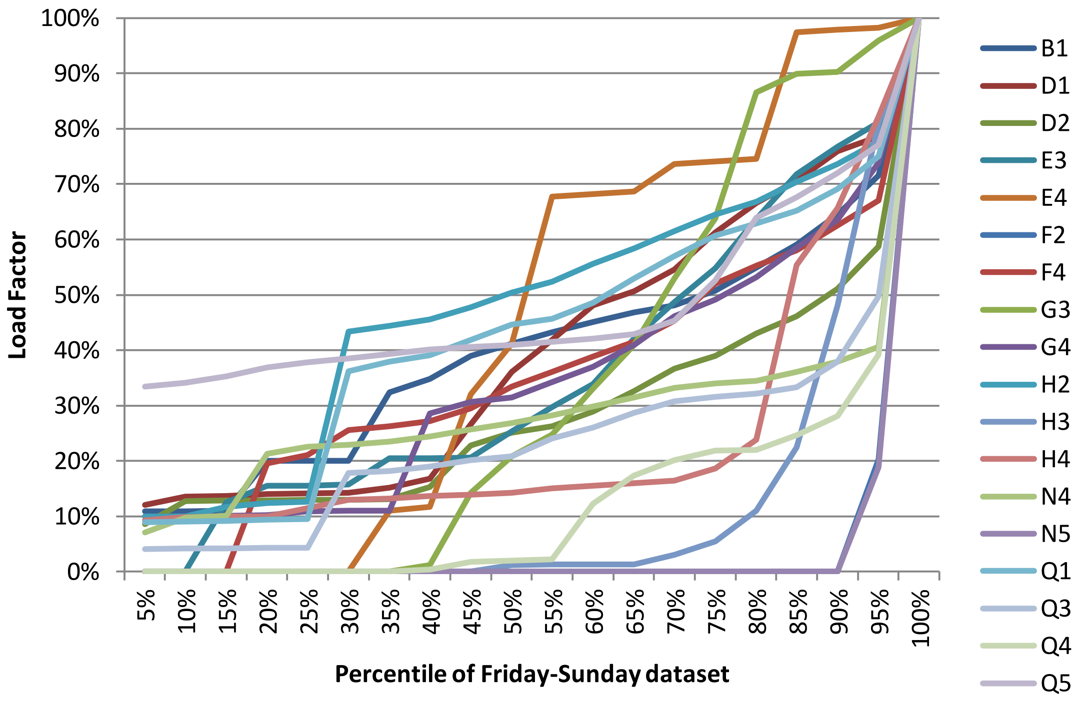


Figure 47 - Load factor percentile profiles, all lighting systems

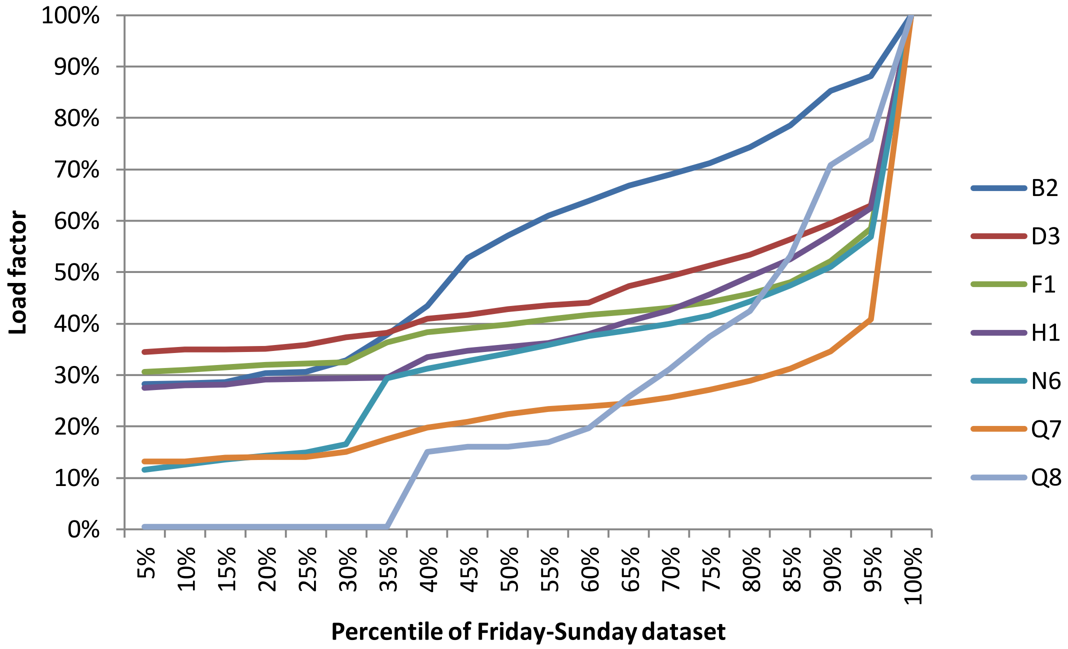


Figure 48 - Load factor percentile profiles, all audio systems

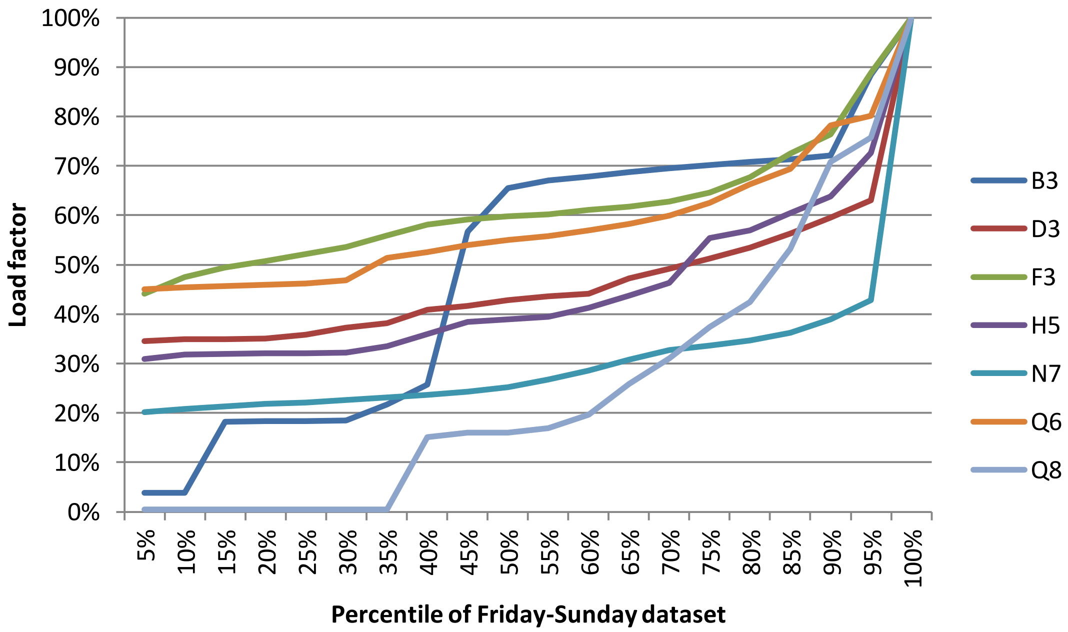


Figure 49 - Load factor percentile profiles, all video systems

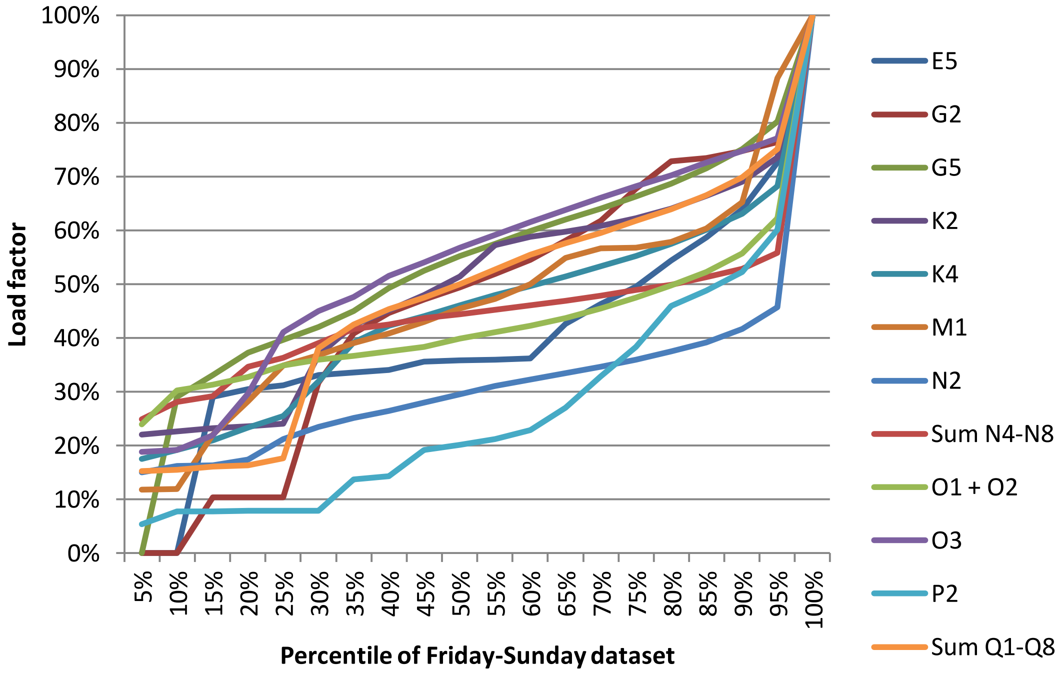


Figure 50 - Load factor percentile profiles, stages

Percentile profiles of lighting show the variety of lighting systems recorded. A 'typical' system could be considered to operated at 10% load factor for at least 25% of the festival, and to only have a load factor greater than 70% for 15% of the weekend. Audio and video both have baseloads present for 30% of the festival, but both have gradual profiles until the final 5% where a sharp increase can be expected. This is especially evident with audio, as the final 5% of the festival can be responsible an additional 150% in demand, as seen in Q7. Stages show a combination of trends present in the three other systems, showing a clear segregation for load factors above 80% and below 80% load factor for all stages, with N2 experiencing this split at 46%

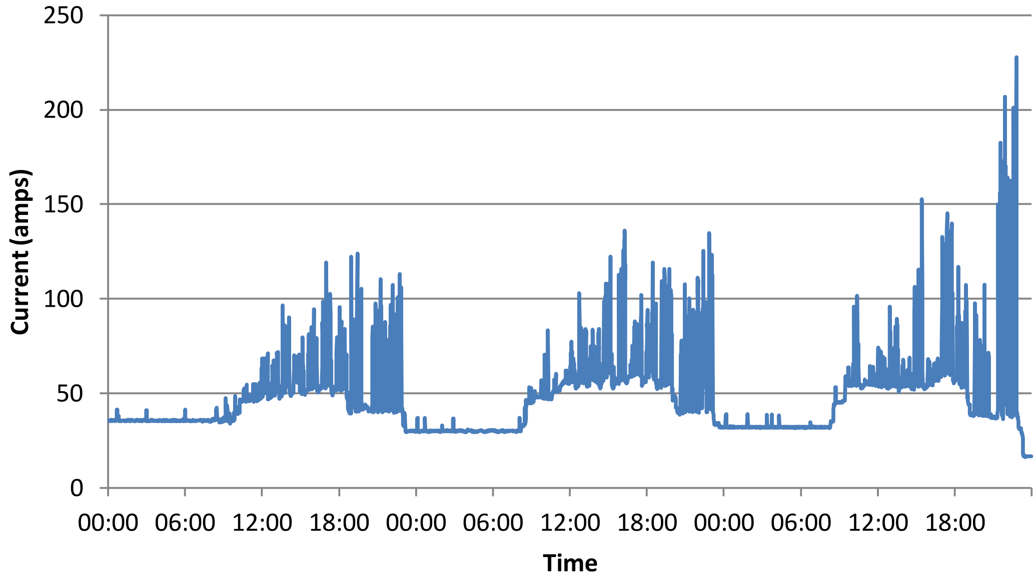


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Figure 51 - Weekend load profile, audio system Q7

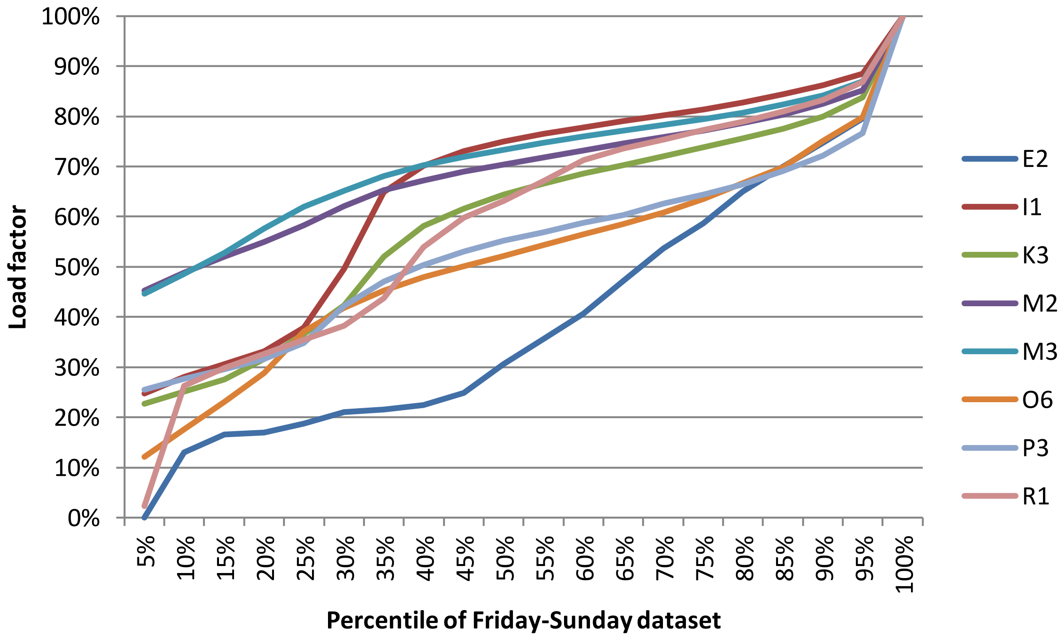

Figure 52 - Load factor percentile profiles, all trader systems

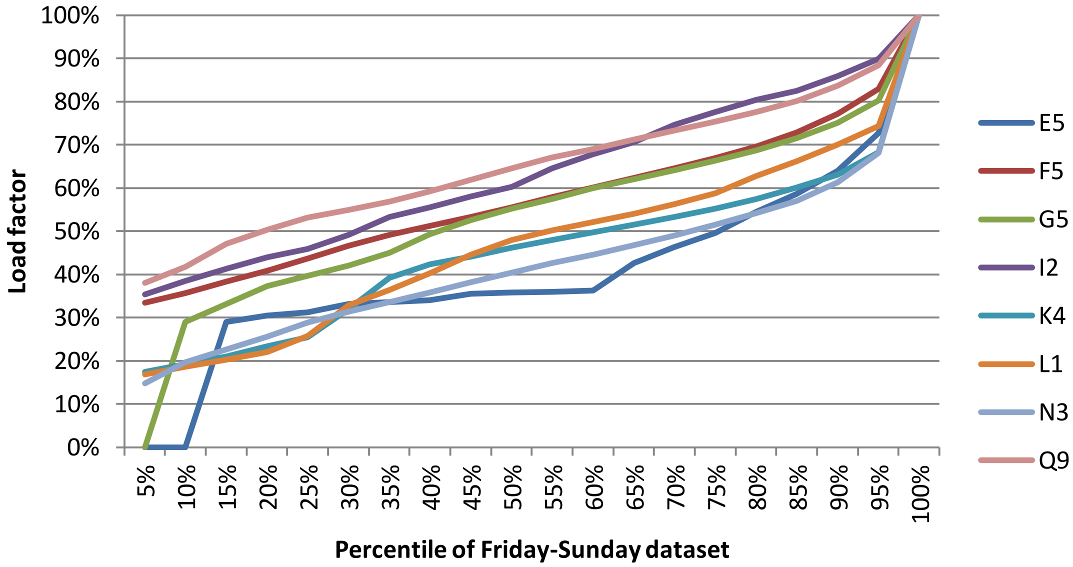

Figure 53 - Load factor percentile profiles, all bar systems

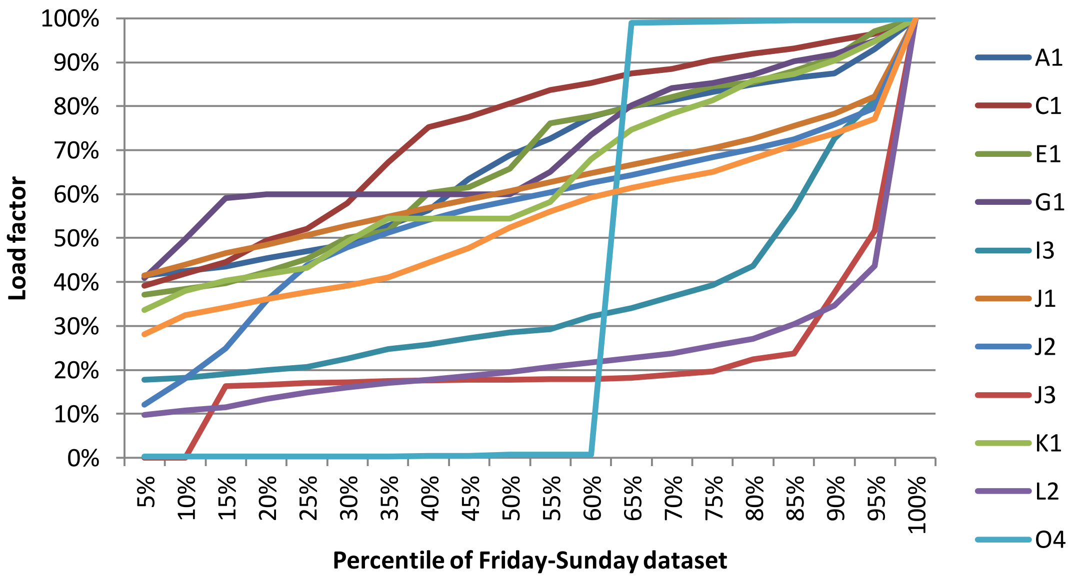

Figure 54 - Load factor percentile profiles, all other systems

In comparison to stages and stage systems, traders and bars have much more even percentile profiles, and show less segregation between load factors. Traders show consistent baseloads, with a clear divide between daytime and night time levels, and the transition period between these times, whereas this divide is missing in some bar systems.

The miscellaneous systems have been displayed as a group to show that each of the trends shown by stages and by traders are shown in other systems too. System O4 is campsite lighting that has been activated and deactivated throughout the festival, therefore displaying binary results. The three systems are all systems that festivals may not dedicate power towards, or if they do it will be part of a larger supply. I3 and L2 are both circuits assigned to tour buses, and J3 is an MRF recycling unit.

6.9 Graphical presentation of the data

In addition to the standardisation of the data through the load profile indicators, the systems should also be presented in comparison to one another in order to gain perspective regarding the energy demands of different systems. The scale and balance between systems will be unique to each system and event, therefore the systems presented below are systems chosen to provide an individual example of demand, allowing for a singular perspective.

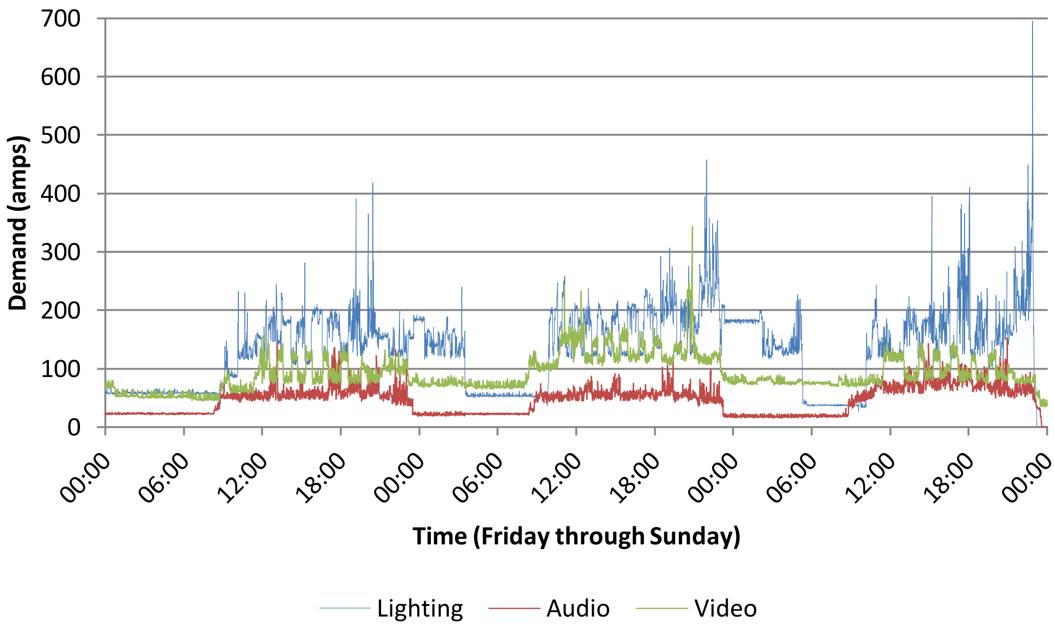

Figure 55- Weekend load profiles for lighting (N4+N5), audio (N8) and video (N7)

Figure 55shows the dominance of stage lighting over other stage systems with the combination of systems from festival N. In comparison, the demands of related traders and infrastructure systems show that comparable demands can be found in other systems as well, particularly traders and tour buses.

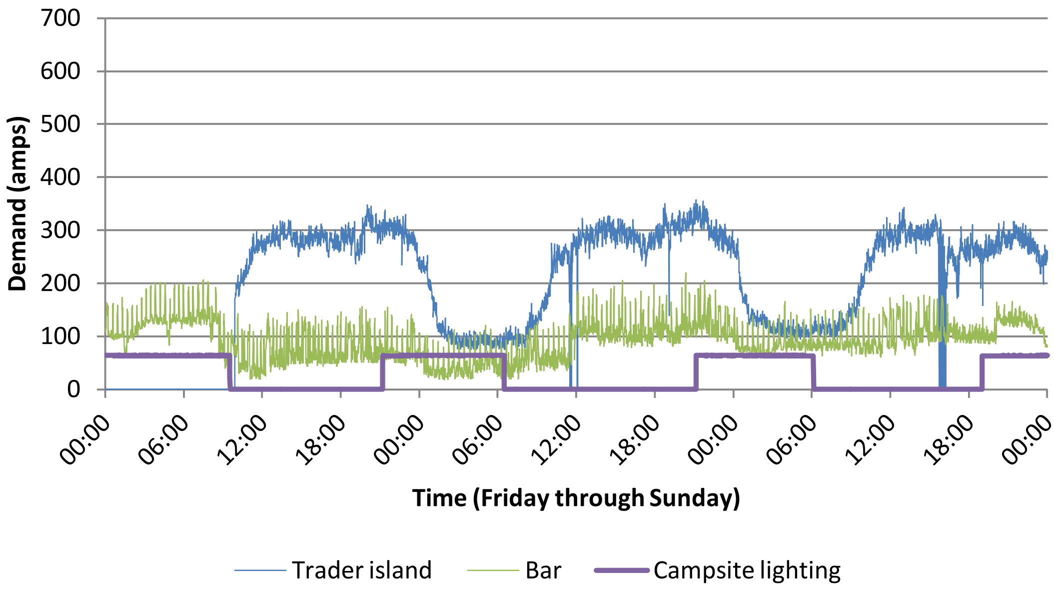

Figure 56 - Weekend load profiles for traders (I1), bars (N3) and campsite lighting (O4)

Demand in trader systems can be greater on average than those on stage systems, but without the potential for large peaks in demand. Traders also show a greater baseload overnight than stage systems, due to the need for refrigeration. The systems shown above represent a single system in each case, and a festival site is likely to have multiple of each one in order to function, so these values should not be considered to represent the entire trader demand of a festival.

The clear usage pattern of the campsite lighting shown above was generated through production staff activating and deactivating the generator each night and each morning, a practice that was not found at other events, despite reducing the load on this generator by 55% in comparison to if it had been left unattended.

Section 7.2 discusses this topic further, in order to identify potential reductions in GHG emissions on the basis energy demands in differing systems.

6.10 Conclusions

This chapter presents the results of the load profile indicators described in section 5.3. These show a number of patterns in the data, as well as allow for a review of the techniques themselves. From these analyses, the following patterns have emerged about the systems themselves:

- Lighting subsystems react to the presence of performers being on stage. All systems show demonstrable increases in consumption during artist performances in comparison to the periods between these performances. The extent of this pattern however is variable, both from system to system, and at times from one artist to the next. This is most noticeable in lighting systems. Stages as a whole can have this effect reduced due to the lesser variations found in audio systems, and the inverse variations found in video systems.
- These variations are due to operational procedure. Given that many systems have been shown to reduce demand between performances, if this practice were undertaken consistently then there could be cost and emissions for the organiser due to improved energy efficiency.
- Video systems can draw more power in between performances, rather than during them.
- In almost every system there is an obvious diurnal variation. Unless a system is specifically designed to work at night, it should be expected that electricity demand on a system reduces at night. This represents an area for potential cost and emission saving, the night period can be considered to last for at least 25% of each festival day.
- Traders represent the most consistent load profiles of any system. Every trader circuit examined followed the same pattern, with electricity demand following in line with the audience patterns at those events.
- Contamination was an issue in many of the LF, MF, PDUC and BDUC indexes in any timeframe other than the overall weekend. This shows that demand does not follow exactly to the boundaries provided by this study, particularly the artist schedule. This represents a problem for this method to overcome, as well as an opportunity for improvement in energy efficiency, to ensure that demand is more responsive to the presence of a performer being on stage.

- BUC and MF analysis of stages suggest that for whole stages there are standard operating practices during specific time periods, but the relationship between these time periods varies. This should be expected, given that the stages monitored are a variety of different sizes and satisfy different purposes at different festivals.
- There may be different operating profiles for large traders in comparison to small traders.
- Traders and bars as a group have similar load profiles during each time subsection with regard to load factor and modulation factor, but the absolute values of consumption vary diurnally.

The following patterns have emerged about the statistical tools used in these analyses:

- Load factor and modulation factor are useful tools to identify the consistency of power demand in systems. Load factor is the more appropriate tool for applying energy savings however, as large differences between peak and average demand are more indicative of operational profiles than large differences between minimum and average demand.
- PDUC and BUC indicators are useful for identifying the location of peaks within the datasets. Peak demand is consistently found during the day during band performances, and baseload demand is consistently found during the night period.
- The metrics in these analyses have been vulnerable to erroneous or exceptional circumstances. In many instances, consistent trends, or levels of performance can be seen, but due to the small sample size, it is unclear whether this would be expected with a larger sample.
- The process of eliminating erroneous low values from baseload and minimum value calculations (MF and BUC) needs development. These factors are still able to serve their purpose by identifying time periods when baseload demand can be expected to occur, however the scale of these factors needs improvement.
- For the purposes of modelling electricity demand at festivals, all of the factors produced can be used, although they should only be used as indicators for any such model, not definitive values. From the work carried out for this thesis, the most useful model is one that considers diurnal variation, and nothing else at this stage. The influence of the artist schedule cannot be uniformly applied across all stage systems beyond an expectation that an artists presence will lead to an increase in demand,

even if there is little variation in average demand. Until a larger dataset is available, ad hoc comparison with similar systems with respect to the system and festival specifications is the recommended course of action. A publicly available, anonymised dataset is the next step in this process.

In addition to the load shape indicators, visual inspection of load profiles and percentile load profiles also shows that the majority of festival systems have separate levels of consumption. Stages and their subsystems have the most significant variances between these levels, and also have a greater detail to their schedule that can be used to predict the timing of these separate load levels. Conversely, stages also have the most variable demand in absolute terms. Traders, bars, and other non-stage systems have clear diurnal distinctions in consumption, and operate primarily at a 'day' level and a 'night' level, although with some variation in demand during these periods. There are distinct levels of demand for each time period, and this diurnal variation represents a potential avenue for emission reduction, as these periods can be predicted and catered for with power supplies that align with the expected demand.

6.10.1 Guidelines for benchmarks

The summary tables in each of the subsections in this chapter can also be used as a guide for benchmarking performance, in line with the following guidelines:

- For systems without significant peaks, load factor should be as close to 1 as possible across all time periods. For systems with significant peaks, load factor should be as low as possible, as this suggests a lowered average demand, rather than an increased maximum demand.
- Benchmarking of modulation factor is of limited use, as values at either limit of 0 or 1 can be considered 'good' values. Minimal values indicate that equipment has had low demand at periods, and values close to 1 indicate consistent demand, which can either mean consistently *low* demand or consistently *high* demand.
- Peak demand uniformity coefficients should mirror the operational schedule of the system e.g. PDUC values during artist performances on stages should equal 1, with much lower values outside of these time periods.
- Baseload uniformity coefficients should ideally be 1 across all time periods, as this suggests that all equipment has been deactivated whenever possible. Realistically

however the BUC values should be the opposite of PDUC values i.e. periods outside of standard operating hours should return values of 1, with operating hours returning smaller values.

- As previously stated, impact factor is not influenced by individual maximum or minimum demands, and is therefore much easier to use for benchmarks. Like PDUC, it should return values that show increased demand during the systems relevant operating schedule.

Using the values in the previous subchapters, a festival should aim to perform in at least in line with the average for each system, and work towards the optimal values in each scenario.

Chapter 7 – Identifying opportunities for GHG emission reduction

Introduction

This chapter identifies opportunities for GHG emission reduction available to festival organisers. These solutions focus on changing overnight operational procedures and changing power sources, using the data analysed in chapter 6. Reductions are quantified in terms of specific terms of power (kWh), fuel (litres), or finance (pound sterling) , as well as percentage reductions that can be applied to systems other than those examined in this research.

The chapter provides practical outcomes from the thesis that can be used by industry professionals, and addresses the third research objective through the results presented in chapter 6, which had addressed the second research objective. The outcomes of chapter 6 are used to identify opportunities for GHG emission reductions through changes in power provision, operation profiles of equipment and using low energy equipment.

All of these opportunities focus on reducing either the emission factor of power provision systems, or reducing the fuel consumption. These opportunities address both the supply and demand for power across a site. Section 7.1 builds on the load profile indicators developed through satisfying objective 2. These highlight regular periods of low demand, which can allow for a reduction in supply, as well as identifying potential demand reductions. 7.2 addresses alternative technologies for both supply and demand, and 7.3 focuses solely on supply reduction based on the excess capacity found during the research.

7.1 Identifying opportunities for GHG emission reduction using load profile indicators

7.1.1 Creating a variable power supply

$$GHG_{i,j} = activity_{i,j} * emission\ \ factor_{i,j}$$

Equation 16 - Calculations of greenhouse gas emissions (DEFRA, 2009, 2010, 2011)

As previously described in chapter 3, the overall goal for reducing GHG emissions is to reduce one of the two values in this equation, either the quantity being examined, or the emission factor. In its base form, this is reducing the emission factor of the fuel, or reducing the quantity of fuel. Renewable energy technologies can be used in some circumstances to reduce the emission factor, however it is clear that diesel technology is currently the industry standard, in the same way that fossil fuels are the standard source of energy in most industrial processes. In an off-grid power network, the activity value is best reduced by reducing demand on the generator and reducing fuel consumption, despite the decrease in fuel efficiency (Diesel Service & Supply, 2009; Perfect Fuel, 2009).

The focus of the data analysis in this thesis has been to produce a series of electricity demand profiles for the key activities at festivals in order to identify periodic changes in consumption. The purpose of this has been to highlight areas of low demand, as low demand will correspond to low fuel efficiency, more fuel being consumed per kWh, and increased fuel consumption above the theoretical optimal level.

In order to provide optimal fuel efficiency for all periods during the festival, there must a mechanism to vary supply in relation to demand. While the power must be made available to enable peak demand, periods exist (e.g. night) where many systems will not be expecting peak demand, and therefore a lesser power supply can be provided. Assuming that no variable power supply, such as the national grid, is available, then a variable supply can only be provided by having multiple power sources for a system, such as one source for periods of high demand and another for periods of low demand. Some generators are already paired in a similar manner in order to provide a backup supply for stage generators, although in this scenario both generators are sized so that they can operate individually if the other generator were to fail. This multi-source system would have a primary source that is sized in the same manner as is the current practice, but would also have a secondary source that is sized based on the night demand of either similar systems or itself from previous years if the data is available. This however is based on the assumption that no changes in operation will occur between the previous system and the current system, which may not be appropriate.

An RET source, rather than a diesel generator, can be used as the secondary power supply. There are many examples of photovoltaic sources being used at festivals for power in systems of limited demand, however these have an inherent problem given that they provide power during the day whereas the majority of low demand periods are found at night. As a result, energy storage through batteries becomes a concern, and if the RET source is not being directly used as the power source at night, it may be more efficient to use the existing diesel generator to charge the batteries. Turning off the diesel generator for a number of hours would reduce the emission factor as well as fuel consumption, although the wider financial, environmental and practical implications would need to be considered in each scenario.

The idea of multiple power sources does have drawbacks. As already mentioned, the idea is based on past results from systems that may not be identical to those which are being used. Even if a system is identical, the operational schedule, and operational behaviour of its users may change between years, which will impact results. This can be accounted for, and the system can be configured to only activate the primary source if necessary, however if the secondary source is not sufficient, then it has served no purpose, and will have been an unnecessary cost for the festival.

In order to avoid this scenario, a single power source that can provide a variable load can be used, such as a variable speed drive (VSD) generator. The advantage of a VSD diesel generator is that it allows the user to configure the generator to provide the amount of power that is deemed necessary, and alter this throughout the weekend. As there is only the single power source, then the potential for wasted costs on secondary power sources is avoided. At present, VSD generators are a new technology in comparison to standard diesel generators, and as they are not the industry standard in the U.K. at present, they will bear an additional cost.

The purpose of these variable power systems will be to reduce GHG emissions at periods of low demand by either improving the fuel efficiency of generators during these periods, or providing power through RET sources. These periods of low demand typically occur during the night period of 0200 – 0800, as shown using the peak demand uniformity coefficient α_{16}. 56% of the systems monitored had a α_{16} value lower than 0.5, showing that in 56% of cases night peak demand was less than half the peak demand of the entire weekend.

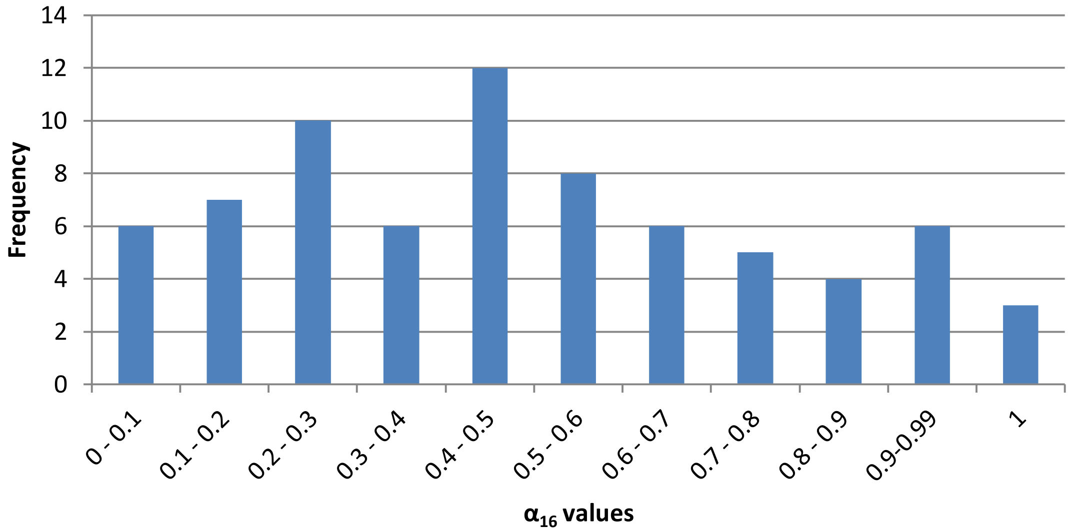

Figure 57 - Histogram of night vs. weekend peak demand uniformity coefficient, α_{16}

This sample includes systems that were designed to be used at night, such as campsite lighting. Having such a significant difference in day and night consumption shows that there are periods of inefficient power provision, and that there is the potential to reduce supply at night in line with these reduced demands.

Generator Size (kW)	Percentage reduction in efficiency compared to full load			
	1/4 Load	1/2 Load	3/4 Load	Full Load
20	50%	13%	8%	0%
30	79%	24%	10%	0%
40	60%	15%	7%	0%
60	50%	21%	6%	0%
75	57%	11%	1%	0%
100	41%	11%	5%	0%
125	36%	10%	4%	0%
135	35%	10%	3%	0%
150	32%	8%	3%	0%
175	29%	7%	2%	0%
200	31%	7%	2%	0%
230	28%	6%	0%	0%
250	27%	6%	1%	0%
300	27%	5%	0%	0%
350	26%	4%	-1%	0%
400	24%	4%	-1%	0%

Table 90 - Reductions in fuel efficiency of diesel generators at part load (Diesel Service & Supply, 2009; Perfect Fuel, 2009)

Fuel efficiency is greatest at loads of at least 75%, with fuel efficiency reducing by as much as 79% at 25% load. Assuming that peak load in all monitored systems equalled the generator operating at full load, then the load factor values will correspond to the loading percentage placed upon the generator. This assumption provides a conservative estimate, as if peak load does not correspond to the maximum output of the generator, then the loading percentage will be lower than the load factor, decreasing efficiency. In this scenario the 56% of systems shown to have a α_{16} value below 0.5 will be at least 4% less efficient at night[7], with 25% of systems recording α_{16} values below 0.25, reducing fuel efficiency by at least 24%.

Generator	Festival size	Function	Generator (kVA)	11am-11pm consumption as %age of total consumption	
				Fuel (litres)	Power (kWh)
A	Major	Bar	200	55%	68%
B	Major	Bar	200	54%	60%
C	Major	Mainstage lighting	2 x 325	52%	76%
D	Major	Mainstage A/V	325	50%	60%
E	Medium	Stage and traders	200	53%	55%
F	Medium	Main stage total	500	50%	58%
G	Medium	Second stage total	250	50%	63%
H	Medium	Production area	150	50%	48%

Table 91 - Fuel and power demand during 1100-2300 period as percentage of total demand

The purpose of VSD generators is to match supply with demand in order to reduce the inequality in fuel efficiency, and allow festivals to capitalise on their diurnal variations. The quantifiable impact of this should be a focal point for any subsequent research in the festival industry. Of the 8 generators monitored, all were found to have average night loading percentages below 25%, with generators F and H operating entirely below 25% loading.

In comparison, the power input curve for VSD generators shows that substantially less power is required to deliver the same levels of output as with standard direct drive generators. While the power input curve is not representative of the overall generator efficiency, clear savings can be made through using VSD generators.

[7] No generator was found to be greater than 500 kVA (400 kW) during the study, so it is assumed that the number of generators throughout the industry that are larger than this will be negligible.

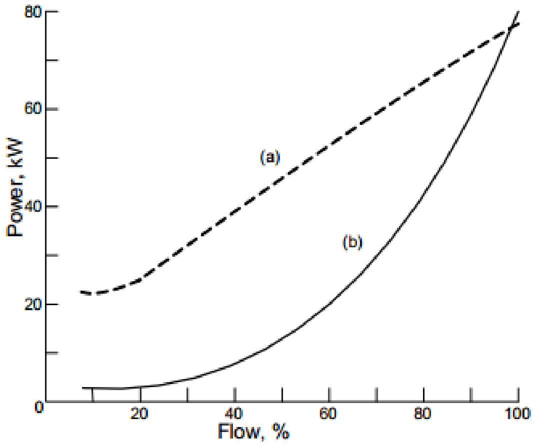

Fig. 2: Input Power for a fan driven by a 100hp Motor
(a) Direct drive and output baffles
(b) Drive via 100 kVA ASD

Figure 58 - Comparison of input power between direct drive and VSD generators (Rooks & Wallace, 2004)

7.1.2 Opportunities for reduction through operational changes

Returning to figure 57, having 44% of systems monitored return α_{16} values greater than 0.5 indicates that demand in many systems overnight can be closer to maximum demand than it is to being switched off. Another measure of night demand is α_{21}, the impact factor comparing average night demand and average demand throughout the festival period, rather than peak demand of these periods.

	α21		
System	**Mean**	**Median**	**Standard Deviation**
Stage lighting	0.31	0.34	0.15
Stage audio	0.50	0.49	0.28
Stage video	0.62	0.73	0.37
Stages	0.50	0.48	0.24
Traders	0.50	0.44	0.17
Bars	0.59	0.61	0.14

Table 92 - Summary statistics for impact factor α_{21} values for stages, traders and bars

Discounting stage lighting, the averaged values for the above system categories shows that most non-lighting systems have a night demand approximately 50-60% of their daytime demand. This figure is a clear target for reduction, as it indicates that equipment is routinely drawing power at night.

In comparison, stages, stage audio and stage video all have α_{21} figures similar to traders and bars which require power overnight for refrigeration, despite not being in operation overnight for any purposes other than for testing. A concern often mentioned during semi-structured interviews with production staff was that equipment was left on overnight in some capacity, be it turned down or on standby, to stop any issues with turning the equipment on again the following morning. Reasons given for this included bad experiences at previous events, concern over the quality of equipment, and using the heat generated by equipment to stop moisture from accumulating. Leaving this equipment on overnight however represents a significant cost to the festival in terms of fuel consumption, as shown in table 91.

Stage Video

The consistency in cross period baseload uniformity coefficients, α_{17} through α_{20}, in stage video systems shows that there is often little difference in baseload throughout the festival. While this shows daytime demand is being reduced where possible, it shows significant opportunities for energy savings at night. Using the night period of between 0200 and 0800, representing 19.5% of the festival period, all but two video systems (B3 and Q8) account for between 15 and 19% of the total power demand. System Q8 is a headliner video system, and is therefore subject to different operational requirements, but system B3 is a generic video rig, and achieves much lower night demand than the other systems. In order to account for operational practices that may not allow for a total switch off, system B3 can be used as an ideal model for other systems. Applying B3's α_{21} value of 0.18 to all other systems shows that video systems could stand to reduce power demand by 10-15% during these periods. See Figure 35 for a comparison of B3's load profile.Q8 is a guest supply, and therefore it already has an optimal operation profile, only being active for preparation and during the show.

	Time period	**B3**	**D3**	**F3**	**H5**	**N7**	**Q6**	**Q8**
Recorded values	Total	939	1087	1599	754	1093	1073	127
	0200-0800	51	196	304	142	164	168	0
Potential value	0200-0800	51	43	59	29	44	42	7
Potential savings	**0200-0800**	**0.0%**	**14.1%**	**15.3%**	**14.9%**	**10.9%**	**11.7%**	**-5.1%**

Table 93 - Potential reductions in video demand due to changes in night demand

Stage Audio

The same issue of baseload uniformity in audio systems also highlights the potential for improvement in overnight operations. Using system N6 as the model for the other systems, savings of up to 11% could be expected.

	Time period	B2	D3	F1	H1	N6	Q7	Q8
Recorded values	Total	1325	1087	615	703	554	588	127
	0200-0800	149	196	97	101	45	69	0
Potential value	0200-0800	108	75	44	51	45	45	12
Potential savings	**0200-0800**	**3.1%**	**11.2%**	**8.7%**	**7.1%**	**0.0%**	**4.0%**	**-9.2%**

Table 94 - Potential reductions in audio demand due to changes in night demand

Stage Lighting

In comparison, stage lighting is a more difficult subset to characterise due to the differing purposes of lighting on each stage, as 'stage lighting' can include safety lighting, front of house lighting, and guest lighting. As a result, the savings estimates presented may not be feasible for all lighting circuits. Lighting systems that are exclusively designated as headliner or front of house lighting have been excluded from these estimates, as they will not represent standard lighting rigs. Discounting system G3, savings of up to 9% could be achieved. G3 is an exceptional circumstance, as it is a small circuit, consisting exclusively of dimmable lights. These lights only represent a part of the other circuits, which will also include a number of other components, and as such G3 is not representative of these other circuits.

Time period	**Recorded values**		**Potential value**	**Potential savings**
	Total	**0200-0800**	**0200-0800**	**0200-0800**
B1	1360	109	47	4.6%
D1	1098	111	40	6.5%
D2	1572	164	55	6.9%
E3	878	88	30	6.6%
F4	1174	103	43	5.2%
G3	388	0	16	-4.2%
G4	1068	66	38	2.7%
H2	2360	281	82	8.4%
N4	1575	190	51	8.9%
Q1	2790	136	104	1.1%
Q3	938	35	35	0.0%

Table 95 - Potential reductions in lighting demand due to changes in night demand

Stages as a whole however are not applicable to this analysis, as each subsystem (lighting, audio and video) will impact upon the overall performance of the stage, and it is each of these systems that should be addressed. The overall savings made upon the stage will be achieved by addressing the individual components, as each stage will have different potential savings for each component. The systems presented above however can be combined to estimate the savings for each festival stage. For systems that provide multiple services, such as D3 providing audio and video, the range of potential savings are presented.

Festival	Total power (kWh)	Optimal power (kWh)	Reduction
B	3624	3521	3%
D	3756	3455	8 - 9%
F	3388	3029	11%
H	3817	3455	9%
N	3222	2962	8%
Q	5389	5207	3%

Table 96 - Potential reductions in stage demand due to changes in night demand

These potential reductions represent all three stage systems maximising their operational efficiency in line with recorded case studies. While reductions in any of these systems are to be encouraged, the key opportunity for savings is found in stage video. These systems have the greatest potential savings individually, represent 27% of the stage power during the festival, and are free of complications such as those found in stage lighting, where lighting may be required for safety purposes.

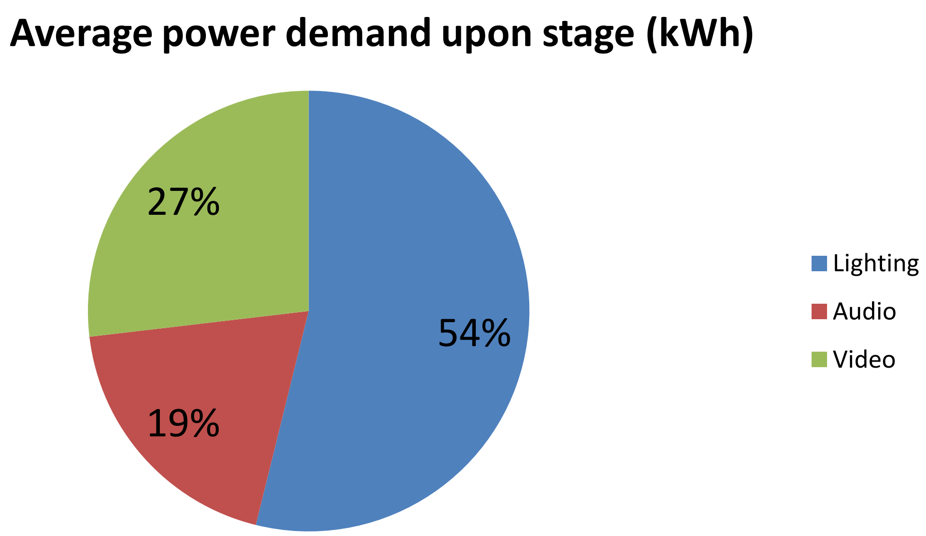

Table 97 - Comparison of average demand for stage subsystems

Traders and bars

The consistent load profiles of traders throughout the research suggest that there is a 'normal' practice in trader circuits, of which all the traders monitored adhered to. While this means that any reductions that can be made could be implemented across all traders, it also means that there is an accepted normal operation with these systems. Potential savings for traders cannot reliably be calculated from the data due to each trader circuit representing a different collection of traders, with each circuit catering for a different number of traders and end users, with differing purposes.

Bars however can be considered to be singular traders, and can therefore be analysed as individual units in the same way that analysing whole stages was of little use, but analysing individual components was. Using L1 as the model for other systems, savings at bars range from 4-9%. The sample includes bars that have small stages incorporated into their power demand, E5, G5 and K4. E5 and K4 show that these savings may not be applicable to bar and stage combinations, although the savings in G5 align with those found in other bars.

	Time period	E5	F5	G5	I2	K4	L1	N3	Q9
Recorded values	Total	619	1910	844	411	827	1347	1013	2650
	0200-0800	110	259	113	54	78	131	148	370
Potential value	0200-0800	52	167	73	37	79	131	87	230
Potential savings	**0200-0800**	**9.3%**	**4.8%**	**4.7%**	**4.2%**	**-0.2%**	**0.0%**	**6.1%**	**5.3%**

Table 98 - Potential reductions in bar demand due to changes in night demand

The quantity of data collected has shown operating profiles for a variety of separate systems. This data includes load profiles that showcase above average energy performance, and can be used as models for similar systems. This approach allows for estimates to be calculated, whilst still ensuring that the optimal model is realistic, rather than being entirely theoretical that could be accused of not accounting for real world elements. The approach has shown that standard bars, stage lighting, stage audio and stage video systems can all reduce demand by at least 5% through reductions in overnight demand.

Overall

Bringing together the potential reductions, all systems could expect to save 10% through changes in operational procedures.

	GHG reduction due to reduced overnight load			
	Lighting	Video	Audio	Bars
Percentage	3 - 11%	10 - 15%	1 - 9%	4 - 9%
Example of savings (kWh)	199	245	121	140
Example of savings (kg CO2e)	200	246	122	141

Table 99- Potential savings from improved operational procedures

7.2 Opportunities for low emission and low energy technologies

RET power sources, such as PV generators, have already been trialled by festivals. These systems have typically been those with low power requirements, reflecting the capacity of temporary RET sources. Conversely, the systems monitored for this research have been the largest systems in place at each event, as only three-phase powerlock systems have been monitored due to their compatibility with non-invasive current transformer based monitoring. Of all the systems monitored, the only system that was a potential candidate for being replaced entirely with an RET power source, a series of production offices at a medium festival, system O5. The maximum demand on this system was 15.98 kW, with average demand of 8.24 kW. These power requirements are within the range of an array constructed from Orion 5 kVA generators by Firefly Solar (Firefly Solar, 2012), although three of these generators will likely have been necessary for this system given that each generator can reach 12 kVA for a brief period, but can only operate continuously at 4.5 kVA. The duration of operation for a production office would make it a desirable candidate for RET replacement, as the production offices will be one of the first systems activated and one of the last ones deactivated, meaning that the estimated cost of £495 (see table 106) during the festival weekend only represents a portion of the cost. However, this system is still not ideal, as three Orion generators would be required to meet the systems maximum demand. Smaller systems however, that are also operational for periods before and after the festival, could benefit from an RET power source.

In order to identify opportunities for generator replacement, the power demands of the festival site must be understood. Discounting systems representing the total festival demand on the national grid (A1, C1, E1, G1 and K1), the following systems are the top and bottom 10% of systems with respect to total power demand, and maximum instantaneous demand.

System key	Year	Festival size (Haworth)	System category	System type	System description	Total kWh	Max kW
∑ Q1-Q8	2012	Major	Stage	Total stage	Main Stage Total	11,212	1,760
∑ Q1-Q3	2012	Major	Stage	Lighting	Main Stage Lighting Total (excl. guest)	6,990	1,185
∑ N4-N8	2012	Large	Stage	Total stage	Mainstage total	5,709	952
M2	2011	Medium	Traders	Traders	Ring of Traders	4,614	480
R1	2012	Medium	Traders/stage	Traders/stage	Traders and Total Small Stage	4,511	566
Q1	2012	Major	Stage	Lighting	Main Stage Lighting 1	3,487	609
∑ D1-D2	2009	Major	Stage	Lighting	Main Stage Lighting - Total	3,337	711

Table 100 - Top 10% of all total system demands (kWh)

System key	Year	Festival size (Haworth)	System category	System type	System description	Total kWh	Max kW
∑ Q1-Q8	2012	Major	Stage	Total stage	Main Stage Total	11,212	1,760
∑ Q1-Q3	2012	Major	Stage	Lighting	Main Stage Lighting Total (excl. guest)	6,990	1,185
∑ N4-N8	2012	Large	Stage	Total stage	Mainstage total	5,709	952
∑ D1-D2	2009	Major	Stage	Lighting	Main Stage Lighting - Total	3,337	711
Q1	2012	Major	Stage	Lighting	Main Stage Lighting 1	3,487	609
Q4	2012	Major	Stage	Lighting	Main Stage Guest Lighting	908	589
R1	2012	Medium	Traders/stage	Traders/stage	Traders and Total Small Stage	4,511	566

Table 101 - Top 10% of maximum system demands (kW)

System key	Year	Festival size (Haworth)	System category	System type	System description	Total kWh	Max kW
O4	2012	Medium	Infrastructure	Campsite	Campsite Lighting	342	64
E4	2010	Small	Stage	Lighting	Second Stage Emergency Lighting	286	47
O2	2012	Medium	Stage	Stage	Stage Right Distribution Point	209	60
J3	2011	Large	Infrastructure	Other	Materials Recovery Facility (MRF)	188	65
Q8	2012	Major	Stage	Audio/Video	Main Stage Guest A/V	159	48
N5	2012	Large	Stage	Lighting	Main Stage Guest Lighting	68	253
F2	2010	Large	Stage	Lighting	Main Stage Guest Lighting	48	141

Table 102 - Bottom 10% of total system demands

System key	Year	Festival size (Haworth)	System category	System type	System description	Total kWh	Max kW
O5	2012	Medium	Infrastructure	Offices	Production Offices	511	69
J3	2011	Large	Infrastructure	Other	Materials Recovery Facility (MRF)	188	65
O4	2012	Medium	Infrastructure	Campsite	Campsite Lighting	342	64
O2	2012	Medium	Stage	Stage	Stage Right Distribution Point	209	60
I2	2011	Large	Traders	Bar	Bar	513	58
Q8	2012	Major	Stage	Audio/Video	Main Stage Guest A/V	159	48
E4	2010	Small	Stage	Lighting	Second Stage Emergency Lighting	286	47

Table 103 - Bottom 10% of maximum system demands

These figures show that while main stage lighting has the greatest maximum demands, the overall demands of traders can be comparable to these systems. This is due to their longer running hours, with less variation during these operating periods. The demands placed upon trader generators will not be influenced by the size of the festival. Instead it is influenced by the number of traders assigned to the generator and their operations, as 10 food traders at a small festival will have similar needs as 10 food traders at a large festival, assuming the quantity of produce sold is similar.

In comparison, many of the smallest demands found on site are from individual systems that have limited running hours, such as emergency, campsite or guest lighting and guest A/V. The lowest instantaneously demanding systems similar systems to the lowest total demanding systems. These are all systems that have little variation during the weekend, all returning $\alpha_5$values in line with the average of the entire set, or higher, signifying that these systems are more stable, and less prone to large instantaneous demands. These are the systems that are most suitable for replacement with an RET power source.

These rankings are inherently biased by the data collected during the research, as systems catering to a large or major festival may need to be larger than those at small and medium festivals in order to achieve the same effect, such as stage systems. Full rankings based on total and instantaneous demand can be found in appendix C.

While RET power sources are not appropriate for the majority of systems monitored, they can be used in certain subsets of these systems, specifically non-food traders. The trader systems monitored consisted of a mix of food traders and non-food traders. During surveys with non-food traders, most reported having very little electrical equipment, often only using lighting and tills within the store. These individual demands can be met through battery storage systems. Cases were found with traders operating entirely from batteries that had been charged prior to the event, and thereby not requiring a power supply from the festival. Moving the responsibility of power to the trader tackles another problem that had been mentioned, which is that there is no connection between power demand and cost for the traders. Traders typically pay for a power supply, and the cost incurred depends upon the size of the supply. This cost is fixed, so there is no incentive to reduce power use, and potentially an incentive to maximise demand in order to get full value from the investment. Deeper analysis of the demands of individual traders should be a topic for future research.

7.2.1 Opportunities for LED lighting

In addition to reducing emissions through alternative technologies in power supply, alternative technologies in power demand can lead to demand and emission reduction, such as LED lighting. There are a variety of low energy equivalents for equipment used at festivals, however LED lighting has been focused on due to the ability to quantify the potential savings through its use beyond a simple power rating comparison, given that this research has focussed on actual demand rather than rated demand.

Of the systems measured, one recorded Radiohead during their 2008/2009 tour during which an all LED lighting rig was employed. The rig has been listed as having a maximum demand of 420 amps (Julies Bicycle, 2013). Assuming the rig was used to full capacity, the maximum lighting demand during Radiohead's performance is 25% lower than found elsewhere in the festival with standard incandescent lighting.

Estimated maximum LED demand	Maximum recorded demand
549	711

Table 104 - Estimated demand for LED lighting and incandescent lighting

The savings are likely to be greater than 25%, as it is unlikely that any lighting system will operate at 100% demand at any one time. This means the 549 amps maximum for LED lighting is being compared to 711 amps for incandescent, despite LED lighting representing an absolute maximum, and incandescent lighting being a recorded maximum, which will be less than the incandescent lamps absolute maximum. Regardless, being able to reduce demand by at least an additional 25% would in turn reduce costs and emissions by 25%. In addition, this reduction will be known prior to the event, allowing for smaller generators to be used on lighting systems, further reducing emissions from wasted fuel consumption through low loading.

7.3 Opportunities for generator downsizing

Eight generators and their total output were recorded in order to compare their power demand and power supply. Table 105 shows the results of this area of study.

Generator	Festival size	Function	Generator (kVA)	Loading percentage				
				Max	Min	Avg (overall)	Avg (day)	Avg (night)
A	Major	Bar	200	38%	7%	17%	22%	9%
B	Major	Bar	200	53%	20%	34%	38%	24%
C	Major	Mainstage lighting	2 x 325	87%	7%	29%	39%	8%
D	Major	Mainstage A/V	325	40%	9%	14%	17%	10%
E	Medium	Stage and traders	200	81%	19%	46%	48%	37%
F	Medium	Main stage total	500	10%	2%	4%	5%	3%
G	Medium	Second stage total	250	36%	7%	19%	22%	10%
H	Medium	Production area	150	13%	4%	7%	7%	7%

Table 105 - Recorded generator loading percentages

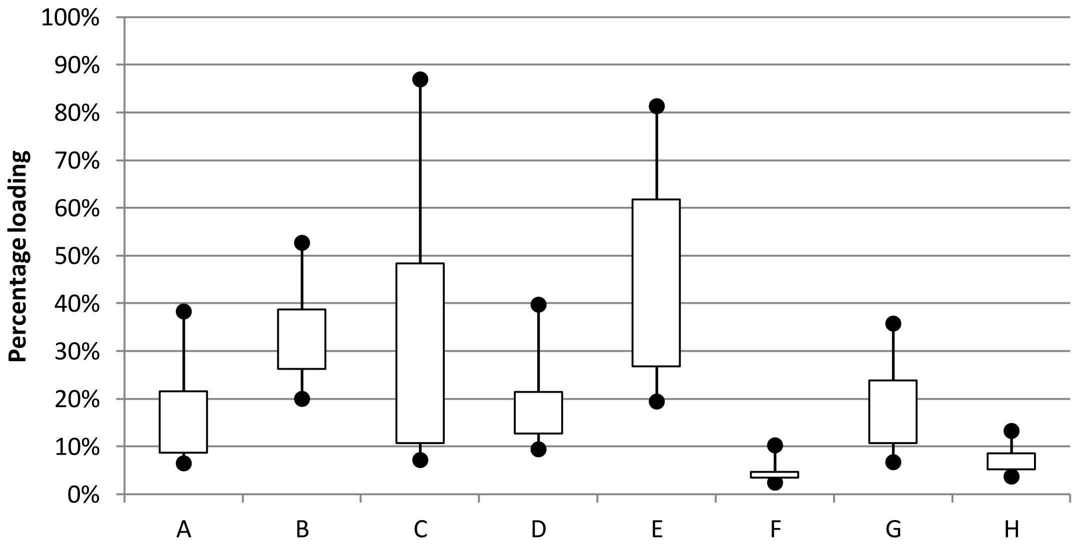

Figure 59 - Maximum, minimum and interquartile range of loading percentage for each generator

The loading percentages highlight a number of issues, some of which are also highlighted by the load profile indicators. The primary issue in this analysis is the maximum loading percentage, as this can be used to indicate if the generator used is appropriate for its affiliated system. These results show a large difference in performance between these generators, with generators C and E recording a maximum demand over 80% of the generator capacity, and generators F and H never achieving higher than 10% and 13% capacity respectively. While this is only of a sample of 8 generators, used for a variety of purposes, having results as low as F and H shows that many generators may be oversized, as well as experiencing systematic periods of low load.

Like load factor, the difference between maximum load and 'standard' load, be it average load or the interquartile range of loads, shows that maximum load is much greater than standard loads. This disparity in some systems should be expected, such as stages, however every generator demonstrates a significant range in demand. This alone is not something that can be looked at as being an indicator of 'good' or 'bad' performance, however it is worth noting as something that must be accounted for in the analysis, showing that neither 'average' or maximum demand does not adequately reflect the entire requirements of the generator.

This difference also highlights the difference between rated power demand and actual power demand. The power systems on site are constructed in order to provide enough power for the rated power for every piece of equipment installed on the site, however these systems only draw peak load for a small period of time during the event (see figure 45), suggesting a difference between rated power demand and actual power demand. Given that the rated power demand needs to available to the equipment, this is unavoidable, however this issue connects to an uncertainty regarding the power requirements of an event, which in turn results in oversized generators.

The power requirements of contractor, trader, production manager or area manager that are given to the festival or power provider can include an additional margin. This can be intentional to ensure that everything in that area runs smoothly, or it can be unintentional. For example, a user can request a power feed of a particular size due to past experience, rather than providing an itemised breakdown of equipment that may indicate a smaller feed would be appropriate (e.g. requesting a 32-amp feed rather than a 16-amp feed, based on past events when only a 32-amp feed was available). This margin has the potential to be added at each stage of planning for an event, and can lead a significantly larger margin in the final specification. This process can be exacerbated by the time restrictions present for a festival. In one instance, the power provider was still waiting to receive final specifications from both traders and production staff two weeks prior to the event, at which point the power provider had already been on site for 10 days. The power provider was instead relying upon estimates and their experience in the field to determine the generator set up that will be required. These communication issues reduce clarity, and introduce the potential for second guessing from each party.

This communication issue is a result of providing appropriate supply for the requested demand. An alternative solution to this problem would be to state the power supply available to each stakeholder, and ensure they budget their energy demand accordingly (Challis 2013a). This solution however removes an element of control regarding the energy security of the event, as it reduces supply and forces demand to conform, rather than reducing demand, and allowing supply to appropriately reduce in line.

Using the fuel estimation model described in chapter 5.4, the following fuel consumption, and associated cost estimates have been produced. Estimates for optimally sized generators have been calculated as well, based on the generator sizes from Diesel Service & Supply (2009), Perfect Fuel (2009), and therefore should be available to an event organiser.

Generator	Festival size	Function	Generator (kVA)	Diesel (l)	Cost
A	Major	Bar	200	1,096	£767
B	Major	Bar	200	1,522	£1,065
C	Major	Mainstage lighting	2 x 325	6,459	£4,521
D	Major	Mainstage A/V	325	3,107	£2,175
E	Medium	Stage and traders	200	1,904	£1,333
F	Medium	Main stage total	500	4,851	£3,396
G	Medium	Second stage total	250	2,562	£1,793
H	Medium	Production area	150	707	£495

Table 106 - Estimated diesel consumption for each generator and associated cost assuming £0.70 per litre diesel, based on price quoted by festival organiser in 2012

Generator	Festival size	Function	Generator (kVA)	Diesel (l)	Cost	Potential savings	
						Money	CO_2e (kg)
A	Major	Bar	100	892	£624	£143	649
B	Major	Bar	125	1,372	£960	£105	477
C	Major	Mainstage lighting	2 x 250	5,918	£4,143	£379	1,720
D	Major	Mainstage A/V	125	1,462	£1,023	£1,152	5,231
E	Medium	Stage and traders	169	1,867	£1,307	£26	118
F	Medium	Main stage total	75	991	£694	£2,702	12,275
G	Medium	Second stage total	125	1,566	£1,096	£697	3,167
H	Medium	Production area	25	272	£190	£305	1,383

Table 107 - Optimal generator specification and diesel consumption for each generator, with associated cost

Generator	Festival size	Function	% savings
A	Major	Bar	19%
B	Major	Bar	10%
C	Major	Mainstage lighting	8%
D	Major	Mainstage A/V	53%
E	Medium	Stage and traders	2%
F	Medium	Main stage total	80%
G	Medium	Second stage total	39%
H	Medium	Production area	62%

Table 108 - Potential percentage savings for each generator

From these 8 generators, it is estimated that £5,508 and 25.02 tonnes CO_2e could have been saved had the generators been downsized, amounting to a 35% reduction in fuel costs and emissions, although there is a substantial difference in potential savings between different systems. Extrapolating this out across the industry, given that 12 million litres of diesel were consumed in 2011 (Johnson & Marchini, 2012), producing 31,600 tonnes of CO_2e, even if the average generator could be downsized to save 2% of fuel, this would account for a reduction of 240,000 litres and 632 tonnes CO_2e, equal to 60 peoples annual GHG emissions, or 50% of Glastonbury Festival's 2009 direct GHG emissions from energy, water and waste (Tsiarta & Heathfield, 2011). The financial impact of a single festival reducing fuel costs by 2% may not be incentive for change on its own, but considering the potential for reductions of 80%, it is an area that festival organisers should at least investigate whether generator downsizing is appropriate for their event through energy monitoring.

In order to determine whether a power system can be altered, the energy security of the festival must be considered. The importance of ensuring energy security should not be understated, as it is as important as energy cost for the festival organisers and for power providers, as any power failures will impact upon the experience of the festival goer and given that there are nearly 1,000 festivals in the UK alone, power failures may deter audiences to avoid a particular event.

With regard to the power provider, they are contractually obliged to ensure that the power requested for system is available. If a failure occurs due to a power provider providing less power than agreed, they will have breached the terms of their contract with the festival.

Because of this scenario, a power provider can only advise a festival on what power would be appropriate for a system, and must adhere to the requirements laid out by the organiser, who in turn determines these requirements based on requirements provided by production staff and other contractors. However, if the power provider is still waiting to receive the official requirements two weeks prior to the festival, it is understandable that a generator can end up being oversized.

These generators will be sized in order to account for the requested demands of each system, as well in line with the performance of similar generators at previous events. Increased capacity will be provided to account for additional, unlisted equipment, as well to account for losses due to poor power quality. For critical systems, such as stages, backup generators are used as well, doubling the size of the power supply being used for these systems.

An additional consideration will be that the fleet of generators available must be used to meet the demands of the entire site, and therefore it may be necessary to provide excessive supply in one area in order to provide a more appropriate supply elsewhere.

7.4 Summary of opportunities for GHG emission reduction

This chapter has identified solutions that can reduce operating costs and GHG emissions on the basis of short time energy monitoring. Based on the case studies examined, the following estimates have been compiled.

		Demand	Supply
Category	**System**	**Reducing overnight load (kWh)**	**Downsizing generators (litres)**
Stages	Stages	3-11%	39-80%
	Lighting	3-11%	8%
	Video	10-15%	53%
	Audio	1-9%	53%
Traders	Bars	4-9%	10-19%
	Traders	-	2%
Infrastructure	Production	-	62%

Table 109 - Potential savings concluded from chapter 7

In addition to these estimates, further reductions can be achieved through the use of low energy technologies. Exact figures for energy reduction through these measures depend on the design of any given system, and how the system would need to be reconfigured to include new technologies whilst still providing the same service. From a purely technical standpoint, amplifiers optimised for their purpose and LED lighting offer efficiency improvements over 'generic' amplifiers and incandescent lighting, which can then allow for further generator downsizing, as well as on site reductions in fuel consumption.

Most systems have a strong diurnal variation, which results in lower demand at night, and lower fuel efficiency. At present, systems at night are estimated to be at least 6% less efficient at night, although this efficiency drop can be as high as 57% in generators of 94 kVA[8] and greater, with power at night costing up to 50% of the fuel bill, despite accounting for as little as 24% of the power demand. This disparity can be addressed through the use of VSD generators, or a smartgrid consisting of multiple source power systems, although both of these represent additional costs as they are either not commonly available in the UK, or require additional equipment. The purpose of these systems is to reduce the quantity of fuel consumed by improving fuel efficiency rates.

Systems with low, consistent demand have been identified as production areas, as well as individual traders and bars. These systems are the most appropriate for the use of RET power sources. The purpose of these systems is to remove the need for on-site diesel consumption entirely.

The ability to monitor energy demand in real time across an entire site would allow a festival to record their actual energy consumption, and would initially allow festivals to address operational inefficiencies such active equipment during periods it should be deactivated (e.g. at night). Once an event has collated this data, it can move forwards with renovating its power provision policy in line with actual demand, rather than expected demand. This data can also be used as a basis for charging traders and other subcontractors for their energy use to encourage energy reductions, as at present a flat rate is paid for power for the entire festival, offering no incentive to reduce consumption.

The ideal power distribution system would be able match supply perfectly with demand. This thesis has identified systemic patterns in consumption for different systems. If this data were available in real time, it would allow variable supply systems to provide power accordingly. With respect to on-site GHG emissions, the optimal variable supply system would be to utilised a smartgrid system, including RET sources for periods of low demand, and a VSD generator for periods of demand beyond the capabilities of a realistic RET source. Using such a system removes the need for fuel consumption during periods of known low demand, improves fuel efficiency during periods of medium demand that require non-RET sources, and still allows for high demands when necessary. Data acquisition is essential in order to realise such a system, if only to ensure that employing one will provide a benefit, and won't impose unnecessary costs, as well as allowing a smartgrid system to actually operate. Such a system utilises models for

[8] This assumes that very few generators are less than 94 kVA. Generators smaller than 94 kVA typically do not use powerlock cabling, and are therefore out of the scope of this research.

expected demand to control and match supply with actual demand, as well as storing excess energy generated ready for periods of high demand and improve energy security. Data collection can improve reliability of the festivals power system, and reduce the risk to energy security on the site. With these data, a festival can make informed decisions regarding its power provision, and can realise the significant benefits outlined throughout this chapter.

Chapter 8 – conclusions

This research has investigated how electricity is used at music festivals in order to reduce the GHG emissions associated with its provision. This overarching aim has been achieved through the analysis of high resolution electricity demand profiles. A series of metrics have been created in order to allow for quick comparison between individual load profiles, allowing a festival to identify areas for reduction in electricity demand. These metrics have been used to identify periods of low demand and low fuel efficiency. By identifying these periods, a festival can subsequently optimise its power provision to reduce fuel consumption, and associated GHG emissions. The metrics can also be used to indicate the suitability of a system for a renewable energy power source.

This thesis has quantified energy demands and GHG emissions for festivals stages, including lighting, audio and video, traders, bars, and a number of infrastructure units such as campsites and production offices. This data has been able to identify opportunities for GHG emission reduction through improvements in limiting equipment use at night and using alternative power sources. These findings contributed to industry guidance on power provision at festivals through conference proceedings, meetings, and the publication of the Power Behind Festivals guide (Johnson, Marchini, et al, 2012).

8.1 Research outcomes

The following section describes how the research objectives were achieved:

Objective 1: Assess the current methodologies used to calculate a festivals carbon footprint.

Two primary carbon footprint models were identified, the Julies Bicycle (JB) model and the Harper model. Both provide similar values for emissions auditing and are built around the same core principles. However the Harper model extends the JB model, designed for sector wide analysis, to include additional estimated values that provide a more realistic value with “fuzzy accuracy” rather than the “false precision” of the JB model. Both models use fuel consumption to calculate GHG emissions from power provision. While this is provides an accurate emissions value, it offers little information on how to reduce this figure, or how it relates to the festival itself.

Objective 2: Use short time interval measurements to analyse power consumption of festival subsystems

A key outcome of the research is the quantification of load profiles for power consumers at festivals through using performance indicators. Identifying predictable patterns of demand means efforts can be focussed on matching supply to demand, rather than matching supply to maximum demand.

The indicators aid the modelling of electricity demand, although the reliability of the modulation factor and baseload uniformity coefficients is limited. Load factor, peak demand uniformity coefficient and impact factor are metrics that should be used to determine the suitability of alternative power systems.

This research has shown that it is possible to collect short time interval energy data at festivals, and that this data is of use to festival organisers and power providers. As a result of this work, further monitoring is due to occur in 2013 at the request of both organisers and power providers, with over 100 additional datasets due to be collected through a knowledge transfer partnership between De Montfort University and a power provider. Once this data is available, benchmark models can be created for each system type, based on the indicators in this thesis, and used as industry standards, as well as allowing individual festivals to audit their own sites to determine more specific benchmarks for themselves, as well as identify opportunities for improvement.

This thesis has produced a model that can be used to convert power load profiles into GHG emissions, providing additional detail to both the JB and Harper methodologies. This model allows organisers to quantify the potential reductions that can be achieved throughout a festival in terms of kWh, fuel consumption and cost savings. The ability to quantify both energy and fuel consumption allows organisers to identify opportunities to reduce emissions, as emissions can only be reduced by either reducing fuel consumption (which is determined by energy consumption) or the emission factor for power provision.

Objective 3: Identify potential strategies for the reduction of GHG emissions from power provision at music festivals

The data gathered to address objective 2 identified opportunities for emission reduction through alterations in power provision in terms of supply and demand. The largest potential savings are achieved through utilising systems that can alter supply to meet demand, and thereby improving fuel efficiency. This can be addressed through using multiple power sources or smartgrids, allowing either more appropriately sized generators to take the load during times of either high or low demand, or by variable speed drive generators that can be scaled to match an expected load profile. RET solutions can be applied also, however the scale of demands for many of the systems monitored is out of the feasible range of RET sources. The research does suggest however that RET sources can be used in situations where demand is continuously low.

The data shows that many generators are oversized, with downsized generators capable of saving at least 2% from fuel bills during the festival weekend, with extreme examples saving up to 80%.While these figures are created from a small sample, the overall load profiles suggest these figures would be found in other systems as well. The reason for oversized systems is in that it improves energy security. However examples such as the main stage that had a maximum demand equal to 10% of the generators capacity indicates that too much spare capacity is provided in some instances.

In addition to altering the methods of power provision, a series of case studies in best practice in subsystems suggest that overnight load in many systems can be reduced by up to 15%. The potential savings found from this work are reiterated below. The nature of each savings category means that these savings cannot simply be added together to obtain a total reduction, as a reduction in one will affect the potential savings in the other. Reductions in demand should be the focus, rather than supply, so as to ensure energy security is not compromised.

Category	System	Potential reductions	
		Reducing overnight load	Downsizing generators
Stages	Stages	3-11%	39-80%
	Lighting	3-11%	8%
	Video	10-15%	53%
	Audio	1-9%	53%
Traders	Bars	4-9%	10-19%
	Traders	-	2%
Infrastructure	Production	-	62%

Table 110 - Potential savings in demand and supply

The greatest opportunities for GHG reductions focus on addressing the disconnect between the supply and demand of energy on a site, and reducing the amount of excess capacity found in some generators, but to also capitalise on systematic periods of high or low demand. An ideal scenario would be to utilise a smartgrid system, where the demands of an area, or even an entire site, can be predicted and influence supply accordingly using a combination of power sources, including RET sources, and using energy storage systems allow the system to take advantage of times when supply is greater than demand.

8.2 Opportunities for further research / applications of the research

The key output of this work has been the creation of the load profile indicators, which have been used for post-event assessments. The next step is to utilise this data in real time, in order to alert the power users about actual consumption and inform power system operation. Such a system would allow for immediate identification of potential energy, fuel and cost reductions. Allowing this data to be available in real time should be a priority for future research. The ability to see excessive demand in real time allows festival staff to turn equipment off and make immediate savings. It also allows power providers to become proactive rather than reactive with respect to addressing any problems encountered, as alarms can be used to alert staff of problems before they occur, rather than waiting for generator failure before realising anything requires attention. Utilising real time data will be critical for the application of any smartgrid system.

Real time monitoring opens a number of avenues for future research, such as measuring the impact of more energy efficient equipment and operation profiles. It also offers an opportunity to improve carbon footprint calculations, through providing a detailed breakdown of when and where on site emissions are occurring.

With respect to lowering emissions in this field, there is a fundamental problem in that at present there is no relationship between supply and demand other than supply needing to be able to meet maximum demand for each isolated area. This represents similarities to national electrification where small interconnected energy sources work together to power what would otherwise be off-grid communities similar to the national grid or smartgrids. Smartgrids allow energy supply and demand to be managed in order to improve energy efficiency and power source utilisation, thereby reducing fuel demand and associated GHG emissions and removing the disconnect found in festival systems. This system would be built around anticipated and real time measured energy demand in order to feed into and control the energy supply, ensuring that energy efficiency is optimised at all times, and that excess energy is stored where possible.

As well identifying this disconnect between supply and demand, the research has highlighted a variety of issues that affect the power provision of a music festival, varying from communication issues and a lack of knowledge regarding energy demand to regular periods of low efficiency and inefficient operating practices. Given the potential savings that have been presented in this thesis, as well as the interest in the research from practitioners, there is an opportunity to apply the findings of this work in order address these issues and reduce GHG emissions at festivals, as well as operational costs.

The issue of energy security will become more significant as the level of supply is reduced. At present, the supply is sized in order to deal with inefficiencies in power transmission and power quality. Power quality issues will become more relevant for future research, as a reduction in power supply will impact upon energy security.

These opportunities for future research have all centred on practical applications of the research within the industry. Further academic research should focus on predictive modelling for energy demand at an event that can be used to quantify predicted demand, building upon the load profile predictions that can be drawn from this research. In addition this research is suitable for use at other temporary events or off-grid systems, such as sporting tournaments, disaster relief, and rural electrification, as well as music venues for longitudinal analysis.

It is surprising that this work has not been previously conducted. Power provision at festivals has been described as being one of the five largest production costs for an event, alongside sanitation, staging, fencing and trackway (Johnson, Marchini, et al, 2012). Considering the increasing cost of fuel in all markets, this research has been able to apply the methods of energy analysis in the built environment in order to offer a valuable insight into how energy is currently used on site, as well as offer opportunities for improvement in future years.

Publications resulting from the thesis

The following documents based upon the work reported in this thesis have been published prior to submission. Three of these have been internal communications between De Montfort University and another organisation, with the final publication being presented to the festival industry as part of the UK Festival Awards, 2012.

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Appendix A

Generator size		Fuel consumption (litres per hour)			
kVA	kW	1/4 load	1/2 load	3/4 load	Full load
25	20	2.27	3.41	4.92	6.06
38	30	4.92	6.81	9.08	10.98
50	40	6.06	8.71	12.11	15.14
75	60	6.81	10.98	14.38	18.17
94	75	9.08	12.87	17.41	23.09
125	100	9.84	15.52	21.96	28.01
156	125	11.73	18.93	26.88	34.45
169	135	12.49	20.44	28.77	37.10
188	150	13.63	22.33	31.80	41.26
219	175	15.52	25.74	36.72	48.07
250	200	17.79	29.15	41.64	54.51
288	230	20.06	33.31	47.32	62.84
313	250	21.58	35.96	51.48	68.14
375	300	25.74	42.78	60.95	81.39
438	350	29.90	49.59	70.79	95.01
500	400	33.69	56.40	80.63	108.26
625	500	41.64	70.03	99.93	135.14
750	600	49.97	83.28	119.24	162.02
938	750	61.70	103.72	148.77	202.14
1250	1000	81.76	137.79	197.22	269.14
1563	1250	101.83	171.48	246.05	336.14
1875	1500	121.89	205.55	294.50	403.15
2188	1750	141.95	239.24	343.34	470.15
2500	2000	162.02	273.31	391.79	537.15
2813	2250	182.08	307.00	440.62	604.15

Table 111 - Diesel consumption chart (Diesel Service & Supply, 2009; Perfect Fuel, 2009)

Variable Drive hp Rating	Efficiency (%)						
	Load, Percent of Drive Rated Power Output						
	1.6	12.5	25	42	50	75	100
5	35	80	88	91	92	94	95
10	41	83	90	93	94	95	96
20	47	86	93	94	95	96	97
30	50	88	93	95	95	96	97
50	46	86	92	95	95	96	97
60	51	87	92	95	95	96	97
75	47	86	93	95	96	97	97
100	55	89	94	95	96	97	97
200	61	81	95	96	96	97	97

Table 112 - VSD efficiency (US. Department of Energy, 2013)

Appendix B

System F5 suffered a failure in the current transformer in one phase midway through recording. In order to still provide a usable value for this system, this phase current was estimated for the remainder of the weekend by adding together the other two phases, based on the previous readings during the weekend. The recorded and estimated values as a whole were returned a two-tail P value of 0.01, rejecting the null hypothesis that the two samples are statistically similar. Excluding the period between 12:30 and 17:00 however, the P value increases to 0.34. During this time period, the recorded value is less than the estimated value, however the two series align from 17:30 until 19:30 when records end. As a result, it was judged that the estimated value can be used to indicate demand.

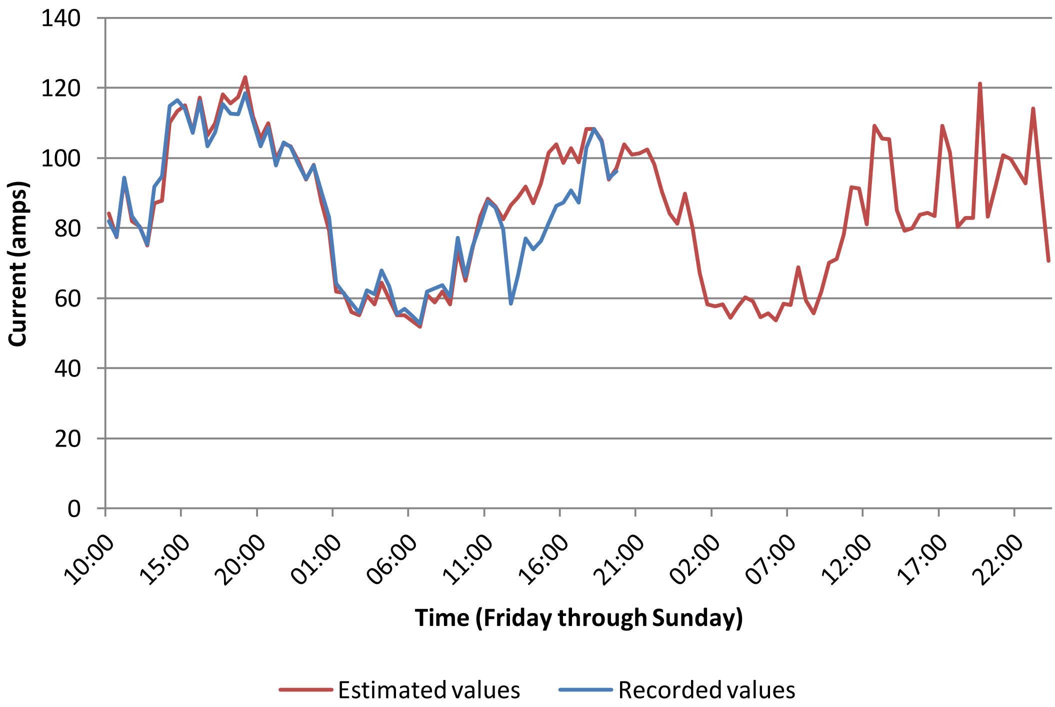

Figure 60 - Recorded and estimated values for one current phase in system F5

Appendix C

Year	Festival	Festival size (Haworth)	System category	System type	System description	System key
2009	A	Small	Total festival	Total festival	Total Festival	A1
	B	Large	Stage	Lighting	Main Stage Lighting	B1
			Stage	Audio	Main Stage Audio	B2
			Stage	Video	Main Stage Video	B3
	C	Medium	Total festival	Total festival	Total Festival	C1
	D	Major	Stage	Lighting	Main Stage Lighting 1	D1
			Stage	Lighting	Main Stage Lighting 2	D2
			Stage	Lighting	Main Stage Lighting - Total	∑ D1-D2
			Stage	Audio/Video	Main Stage Audio + Video	D3
2010	E	Small	Total festival	Total festival	Total Festival	E1
			Traders	Traders	Total Traders	E2
			Stage	Lighting	Second Stage Lighting	E3
			Stage	Lighting	Second Stage Emergency Lighting	E4
			Traders/stage	Bar/total stage	Bar & Total Small Stage	E5
	F	Large	Stage	Audio	Main Stage Audio	F1
			Stage	Lighting	Main Stage Guest Lighting	F2
			Stage	Video	Main Stage Video	F3
			Stage	Lighting	Main Stage Lighting	F4
			Traders	Bar	Bar	F5
	G	Medium	Total festival	Total festival	Total Festival	G1
			Stage	Total stage	Second Stage Total	G2
			Stage	Lighting	Second Stage Dimmable Lighting	G3
			Stage	Lighting	Main Stage Lighting	G4
			Traders/stage	Bar/total stage	Bar and Total Small Stage	G5
	H	Major	Stage	Audio	Main Stage Audio	H1
			Stage	Lighting	Main Stage Lighting	H2
			Stage	Lighting	Main Stage Guest Lighting	H3
			Stage	Lighting	Main Stage FOH Lighting	H4
			Stage	Video	Main Stage Video	H5
2011	I	Large	Traders	Traders	Ring of Traders	I1
			Traders	Bar	Bar	I2
			Infrastructure	Tour buses	Main Stage Tour Buses	I3
			Infrastructure	Other	Crew Catering	I4
	J	Large	Infrastructure	Campsite	Production Campsite 1	J1
			Infrastructure	Campsite	Production Campsite 2	J2
			Infrastructure	Other	Materials Recovery Facility (MRF)	J3
	K	Medium	Total festival	Total festival	Total Festival	K1
			Stage	Total stage	Second Stage Total	K2
			Traders	Traders	Ring Of Traders	K3
			Traders/stage	Bar/total stage	Bar and Total Small Stage	K4
	L	Major	Traders	Bar	Bar	L1
			Infrastructure	Tour buses	Main Stage Tour Buses	L2
	M	Medium	Stage	Total stage	Second Stage Total	M1
			Traders	Traders	Ring of Traders	M2
			Traders	Traders	Ring of Traders	M3
2012	N	Large	Infrastructure	Other	Crew Catering	N1
			Stage	Total stage	Second Stage Total	N2
			Traders	Bar	Bar	N3
			Stage	Lighting	Main Stage Lighting	N4
			Stage	Lighting	Main Stage Guest Lighting	N5
			Stage	Audio	Main Stage Audio	N6
			Stage	Video	Main Stage Video	N7
			Stage	Other	Main Stage 'Local'	N8
			Stage	Total stage	Mainstage total	∑ N4-N8
	O	Medium	Stage	Stage	Stage Left Distribution Point	O1
			Stage	Stage	Stage Right Distribution Point	O2
			Stage	Stage	Main Stage Total	∑ O1-O2
			Stage	Stage	Second Stage Total	O3
			Infrastructure	Campsite	Campsite Lighting	O4
			Infrastructure	Offices	Production Offices	O5
			Traders	Traders	Ring of Traders	O6
	P	Medium	Total festival	Total festival	Total Festival	P1
			Stage	Stage	Main Stage Total	P2
			Traders	Traders	Ring of Traders	P3
	Q	Major	Stage	Lighting	Main Stage Lighting 1	Q1
			Stage	Lighting	Main Stage Lighting 2	Q2
			Stage	Lighting	Main Stage Lighting 3	Q3
			Stage	Lighting	Main Stage Lighting Total (excl. guest)	∑ Q1-Q3
			Stage	Lighting	Main Stage Guest Lighting	Q4
			Stage	Lighting	Main Stage FOH Lighting	Q5
			Stage	Audio/Video	Main Stage Video & FOH Audio	Q6
			Stage	Audio	Audio	Q7
			Stage	Audio/Video	Main Stage Guest A/V	Q8
			Stage	Total stage	Main Stage Total	∑ Q1-Q8
			Traders	Bar	Bar	Q9
	R	Medium	Traders/stage	Traders/stage	Traders and Total Small Stage	R1

Table 113 - System key for systems monitored

Year	Festival	Festival size (Haworth)	System category	System type	System description	System key	Total kWh	Max kW
2009	A	Small	Total festival	Total festival	Total Festival	A1	9,713	1,043
	B	Large	Stage	Lighting	Main Stage Lighting	B1	1,700	319
			Stage	Audio	Main Stage Audio	B2	1,657	229
			Stage	Video	Main Stage Video	B3	1,173	186
	C	Medium	Total festival	Total festival	Total Festival	C1	13,823	1,340
	D	Major	Stage	Lighting	Main Stage Lighting 1	D1	1,372	259
			Stage	Lighting	Main Stage Lighting 2	D2	1,965	511
			Stage	Lighting	Main Stage Lighting - Total	∑ D1-D2	3,337	711
			Stage	Audio/Video	Main Stage Audio + Video	D3	1,359	221
2010	E	Small	Total festival	Total festival	Total Festival	E1	9,434	1,017
			Traders	Traders	Total Traders	E2	1,472	280
			Stage	Lighting	Second Stage Lighting	E3	1,098	226
			Stage	Lighting	Second Stage Emergency Lighting	E4	286	47
			Traders/stage	Bar/total stage	Bar & Total Small Stage	E5	774	144
	F	Large	Stage	Audio	Main Stage Audio	F1	769	137
			Stage	Lighting	Main Stage Guest Lighting	F2	48	141
			Stage	Video	Main Stage Video	F3	1,999	237
			Stage	Lighting	Main Stage Lighting	F4	1,467	311
			Traders	Bar	Bar	F5	2,388	301
	G	Medium	Total festival	Total festival	Total Festival	G1	10,915	1,117
			Stage	Total stage	Second Stage Total	G2	1,557	250
			Stage	Lighting	Second Stage Dimmable Lighting	G3	484	105
			Stage	Lighting	Main Stage Lighting	G4	1,335	284
			Traders/stage	Bar/total stage	Bar and Total Small Stage	G5	1,055	143
	H	Major	Stage	Audio	Main Stage Audio	H1	879	160
			Stage	Lighting	Main Stage Lighting	H2	2,950	465
			Stage	Lighting	Main Stage Guest Lighting	H3	505	310
			Stage	Lighting	Main Stage FOH Lighting	H4	422	122
			Stage	Video	Main Stage Video	H5	943	152
2011	I	Large	Traders	Traders	Ring of Traders	I1	3,242	358
			Traders	Bar	Bar	I2	513	58
			Infrastructure	Tour buses	Main Stage Tour Buses	I3	438	88
			Infrastructure	Other	Crew Catering	I4	-	-
	J	Large	Infrastructure	Campsite	Production Campsite 1	J1	1,916	222
			Infrastructure	Campsite	Production Campsite 2	J2	1,364	180
			Infrastructure	Other	Materials Recovery Facility (MRF)	J3	188	65
	K	Medium	Total festival	Total festival	Total Festival	K1	10,273	1,165
			Stage	Total stage	Second Stage Total	K2	1,881	275
			Traders	Traders	Ring Of Traders	K3	2,115	262
			Traders/stage	Bar/total stage	Bar and Total Small Stage	K4	1,033	170
	L	Major	Traders	Bar	Bar	L1	1,684	267
			Infrastructure	Tour buses	Main Stage Tour Buses	L2	1,498	485
	M	Medium	Stage	Total stage	Second Stage Total	M1	1,302	205
			Traders	Traders	Ring of Traders	M2	4,614	480
			Traders	Traders	Ring of Traders	M3	2,914	294
2012	N	Large	Infrastructure	Other	Crew Catering	N1	1,933	382
			Stage	Total stage	Second Stage Total	N2	1,532	369
			Traders	Bar	Bar	N3	1,266	220
			Stage	Lighting	Main Stage Lighting	N4	1,968	535
			Stage	Lighting	Main Stage Guest Lighting	N5	68	253
			Stage	Audio	Main Stage Audio	N6	692	153
			Stage	Video	Main Stage Video	N7	1,366	344
			Stage	Other	Main Stage 'Local'	N8	1,614	221
			Stage	Total stage	Mainstage total	∑ N4-N8	5,709	952
	O	Medium	Stage	Stage	Stage Left Distribution Point	O1	838	169
			Stage	Stage	Stage Right Distribution Point	O2	209	60
			Stage	Stage	Main Stage Total	∑ O1-O2	1,047	179
			Stage	Stage	Second Stage Total	O3	2,320	311
			Infrastructure	Campsite	Campsite Lighting	O4	342	64
			Infrastructure	Offices	Production Offices	O5	511	69
			Traders	Traders	Ring of Traders	O6	529	76
	P	Medium	Total festival	Total festival	Total Festival	P1	-	-
			Stage	Stage	Main Stage Total	P2	896	254
			Traders	Traders	Ring of Traders	P3	2,042	280
	Q	Major	Stage	Lighting	Main Stage Lighting 1	Q1	3,487	609
			Stage	Lighting	Main Stage Lighting 2	Q2	-	-
			Stage	Lighting	Main Stage Lighting 3	Q3	1,173	384
			Stage	Lighting	Main Stage Lighting Total (excl. guest)	∑ Q1-Q3	6,990	1,185
			Stage	Lighting	Main Stage Guest Lighting	Q4	908	589
			Stage	Lighting	Main Stage FOH Lighting	Q5	1,078	163
			Stage	Audio/Video	Main Stage Video & FOH Audio	Q6	1,342	167
			Stage	Audio	Audio	Q7	735	228
			Stage	Audio/Video	Main Stage Guest A/V	Q8	159	48
			Stage	Total stage	Main Stage Total	∑ Q1-Q8	11,212	1,760
			Traders	Bar	Bar	Q9	3,313	367
	R	Medium	Traders/stage	Traders/stage	Traders and Total Small Stage	R1	4,511	566

Table 114 - Summary values for each system in system key order

System key	Year	Festival size (Haworth)	System category	System type	System description	Total kWh	Max kW
C1	2009	Medium	Total festival	Total festival	Total Festival	13,823	1,340
∑ Q1-Q8	2012	Major	Stage	Total stage	Main Stage Total	11,212	1,760
G1	2010	Medium	Total festival	Total festival	Total Festival	10,915	1,117
K1	2011	Medium	Total festival	Total festival	Total Festival	10,273	1,165
A1	2009	Small	Total festival	Total festival	Total Festival	9,713	1,043
E1	2010	Small	Total festival	Total festival	Total Festival	9,434	1,017
∑ Q1-Q3	2012	Major	Stage	Lighting	Main Stage Lighting Total (excl. guest)	6,990	1,185
∑ N4-N8	2012	Large	Stage	Total stage	Mainstage total	5,709	952
M2	2011	Medium	Traders	Traders	Ring of Traders	4,614	480
R1	2012	Medium	Traders/stage	Traders/stage	Traders and Total Small Stage	4,511	566
Q1	2012	Major	Stage	Lighting	Main Stage Lighting 1	3,487	609
∑ D1-D2	2009	Major	Stage	Lighting	Main Stage Lighting - Total	3,337	711
Q9	2012	Major	Traders	Bar	Bar	3,313	367
I1	2011	Large	Traders	Traders	Ring of Traders	3,242	358
H2	2010	Major	Stage	Lighting	Main Stage Lighting	2,950	465
M3	2011	Medium	Traders	Traders	Ring of Traders	2,914	294
F5	2010	Large	Traders	Bar	Bar	2,388	301
O3	2012	Medium	Stage	Stage	Second Stage Total	2,320	311
K3	2011	Medium	Traders	Traders	Ring Of Traders	2,115	262
P3	2012	Medium	Traders	Traders	Ring of Traders	2,042	280
F3	2010	Large	Stage	Video	Main Stage Video	1,999	237
N4	2012	Large	Stage	Lighting	Main Stage Lighting	1,968	535
D2	2009	Major	Stage	Lighting	Main Stage Lighting 2	1,965	511
N1	2012	Large	Infrastructure	Other	Crew Catering	1,933	382
J1	2011	Large	Infrastructure	Campsite	Production Campsite 1	1,916	222
K2	2011	Medium	Stage	Total stage	Second Stage Total	1,881	275
B1	2009	Large	Stage	Lighting	Main Stage Lighting	1,700	319
L1	2011	Major	Traders	Bar	Bar	1,684	267
B2	2009	Large	Stage	Audio	Main Stage Audio	1,657	229
N8	2012	Large	Stage	Other	Main Stage 'Local'	1,614	221
G2	2010	Medium	Stage	Total stage	Second Stage Total	1,557	250
N2	2012	Large	Stage	Total stage	Second Stage Total	1,532	369
L2	2011	Major	Infrastructure	Tour buses	Main Stage Tour Buses	1,498	485
E2	2010	Small	Traders	Traders	Total Traders	1,472	280
F4	2010	Large	Stage	Lighting	Main Stage Lighting	1,467	311
D1	2009	Major	Stage	Lighting	Main Stage Lighting 1	1,372	259
N7	2012	Large	Stage	Video	Main Stage Video	1,366	344
J2	2011	Large	Infrastructure	Campsite	Production Campsite 2	1,364	180
D3	2009	Major	Stage	Audio/Video	Main Stage Audio + Video	1,359	221
Q6	2012	Major	Stage	Audio/Video	Main Stage Video & FOH Audio	1,342	167
G4	2010	Medium	Stage	Lighting	Main Stage Lighting	1,335	284
M1	2011	Medium	Stage	Total stage	Second Stage Total	1,302	205
N3	2012	Large	Traders	Bar	Bar	1,266	220
B3	2009	Large	Stage	Video	Main Stage Video	1,173	186
Q3	2012	Major	Stage	Lighting	Main Stage Lighting 3	1,173	384
E3	2010	Small	Stage	Lighting	Second Stage Lighting	1,098	226
Q5	2012	Major	Stage	Lighting	Main Stage FOH Lighting	1,078	163
G5	2010	Medium	Traders/stage	Bar/total stage	Bar and Total Small Stage	1,055	143
∑ O1-O2	2012	Medium	Stage	Stage	Main Stage Total	1,047	179
K4	2011	Medium	Traders/stage	Bar/total stage	Bar and Total Small Stage	1,033	170
H5	2010	Major	Stage	Video	Main Stage Video	943	152
Q4	2012	Major	Stage	Lighting	Main Stage Guest Lighting	908	589
P2	2012	Medium	Stage	Stage	Main Stage Total	896	254
H1	2010	Major	Stage	Audio	Main Stage Audio	879	160
O1	2012	Medium	Stage	Stage	Stage Left Distribution Point	838	169
E5	2010	Small	Traders/stage	Bar/total stage	Bar & Total Small Stage	774	144
F1	2010	Large	Stage	Audio	Main Stage Audio	769	137
Q7	2012	Major	Stage	Audio	Audio	735	228
N6	2012	Large	Stage	Audio	Main Stage Audio	692	153
O6	2012	Medium	Traders	Traders	Ring of Traders	529	76
I2	2011	Large	Traders	Bar	Bar	513	58
O5	2012	Medium	Infrastructure	Offices	Production Offices	511	69
H3	2010	Major	Stage	Lighting	Main Stage Guest Lighting	505	310
G3	2010	Medium	Stage	Lighting	Second Stage Dimmable Lighting	484	105
I3	2011	Large	Infrastructure	Tour buses	Main Stage Tour Buses	438	88
H4	2010	Major	Stage	Lighting	Main Stage FOH Lighting	422	122
O4	2012	Medium	Infrastructure	Campsite	Campsite Lighting	342	64
E4	2010	Small	Stage	Lighting	Second Stage Emergency Lighting	286	47
O2	2012	Medium	Stage	Stage	Stage Right Distribution Point	209	60
J3	2011	Large	Infrastructure	Other	Materials Recovery Facility (MRF)	188	65
Q8	2012	Major	Stage	Audio/Video	Main Stage Guest A/V	159	48
N5	2012	Large	Stage	Lighting	Main Stage Guest Lighting	68	253
F2	2010	Large	Stage	Lighting	Main Stage Guest Lighting	48	141
I4	2011	Large	Infrastructure	Other	Crew Catering	-	-
P1	2012	Medium	Total festival	Total festival	Total Festival	-	-
Q2	2012	Major	Stage	Lighting	Main Stage Lighting 2	-	-

Table 115 - Summary values for each system sorted by total demand (kWh)

System key	Year	Festival size (Haworth)	System category	System type	System description	Total kWh	Max kW
∑ Q1-Q8	2012	Major	Stage	Total stage	Main Stage Total	11,212	1,760
C1	2009	Medium	Total festival	Total festival	Total Festival	13,823	1,340
∑ Q1-Q3	2012	Major	Stage	Lighting	Main Stage Lighting Total (excl. guest)	6,990	1,185
K1	2011	Medium	Total festival	Total festival	Total Festival	10,273	1,165
G1	2010	Medium	Total festival	Total festival	Total Festival	10,915	1,117
A1	2009	Small	Total festival	Total festival	Total Festival	9,713	1,043
E1	2010	Small	Total festival	Total festival	Total Festival	9,434	1,017
∑ N4-N8	2012	Large	Stage	Total stage	Mainstage total	5,709	952
∑ D1-D2	2009	Major	Stage	Lighting	Main Stage Lighting - Total	3,337	711
Q1	2012	Major	Stage	Lighting	Main Stage Lighting 1	3,487	609
Q4	2012	Major	Stage	Lighting	Main Stage Guest Lighting	908	589
R1	2012	Medium	Traders/stage	Traders/stage	Traders and Total Small Stage	4,511	566
N4	2012	Large	Stage	Lighting	Main Stage Lighting	1,968	535
D2	2009	Major	Stage	Lighting	Main Stage Lighting 2	1,965	511
L2	2011	Major	Infrastructure	Tour buses	Main Stage Tour Buses	1,498	485
M2	2011	Medium	Traders	Traders	Ring of Traders	4,614	480
H2	2010	Major	Stage	Lighting	Main Stage Lighting	2,950	465
Q3	2012	Major	Stage	Lighting	Main Stage Lighting 3	1,173	384
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N2	2012	Large	Stage	Total stage	Second Stage Total	1,532	369
Q9	2012	Major	Traders	Bar	Bar	3,313	367
I1	2011	Large	Traders	Traders	Ring of Traders	3,242	358
N7	2012	Large	Stage	Video	Main Stage Video	1,366	344
B1	2009	Large	Stage	Lighting	Main Stage Lighting	1,700	319
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O3	2012	Medium	Stage	Stage	Second Stage Total	2,320	311
H3	2010	Major	Stage	Lighting	Main Stage Guest Lighting	505	310
F5	2010	Large	Traders	Bar	Bar	2,388	301
M3	2011	Medium	Traders	Traders	Ring of Traders	2,914	294
G4	2010	Medium	Stage	Lighting	Main Stage Lighting	1,335	284
E2	2010	Small	Traders	Traders	Total Traders	1,472	280
P3	2012	Medium	Traders	Traders	Ring of Traders	2,042	280
K2	2011	Medium	Stage	Total stage	Second Stage Total	1,881	275
L1	2011	Major	Traders	Bar	Bar	1,684	267
K3	2011	Medium	Traders	Traders	Ring Of Traders	2,115	262
D1	2009	Major	Stage	Lighting	Main Stage Lighting 1	1,372	259
P2	2012	Medium	Stage	Stage	Main Stage Total	896	254
N5	2012	Large	Stage	Lighting	Main Stage Guest Lighting	68	253
G2	2010	Medium	Stage	Total stage	Second Stage Total	1,557	250
F3	2010	Large	Stage	Video	Main Stage Video	1,999	237
B2	2009	Large	Stage	Audio	Main Stage Audio	1,657	229
Q7	2012	Major	Stage	Audio	Audio	735	228
E3	2010	Small	Stage	Lighting	Second Stage Lighting	1,098	226
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D3	2009	Major	Stage	Audio/Video	Main Stage Audio + Video	1,359	221
N8	2012	Large	Stage	Other	Main Stage 'Local'	1,614	221
N3	2012	Large	Traders	Bar	Bar	1,266	220
M1	2011	Medium	Stage	Total stage	Second Stage Total	1,302	205
B3	2009	Large	Stage	Video	Main Stage Video	1,173	186
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K4	2011	Medium	Traders/stage	Bar/total stage	Bar and Total Small Stage	1,033	170
O1	2012	Medium	Stage	Stage	Stage Left Distribution Point	838	169
Q6	2012	Major	Stage	Audio/Video	Main Stage Video & FOH Audio	1,342	167
Q5	2012	Major	Stage	Lighting	Main Stage FOH Lighting	1,078	163
H1	2010	Major	Stage	Audio	Main Stage Audio	879	160
N6	2012	Large	Stage	Audio	Main Stage Audio	692	153
H5	2010	Major	Stage	Video	Main Stage Video	943	152
E5	2010	Small	Traders/stage	Bar/total stage	Bar & Total Small Stage	774	144
G5	2010	Medium	Traders/stage	Bar/total stage	Bar and Total Small Stage	1,055	143
F2	2010	Large	Stage	Lighting	Main Stage Guest Lighting	48	141
F1	2010	Large	Stage	Audio	Main Stage Audio	769	137
H4	2010	Major	Stage	Lighting	Main Stage FOH Lighting	422	122
G3	2010	Medium	Stage	Lighting	Second Stage Dimmable Lighting	484	105
I3	2011	Large	Infrastructure	Tour buses	Main Stage Tour Buses	438	88
O6	2012	Medium	Traders	Traders	Ring of Traders	529	76
O5	2012	Medium	Infrastructure	Offices	Production Offices	511	69
J3	2011	Large	Infrastructure	Other	Materials Recovery Facility (MRF)	188	65
O4	2012	Medium	Infrastructure	Campsite	Campsite Lighting	342	64
O2	2012	Medium	Stage	Stage	Stage Right Distribution Point	209	60
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Q8	2012	Major	Stage	Audio/Video	Main Stage Guest A/V	159	48
E4	2010	Small	Stage	Lighting	Second Stage Emergency Lighting	286	47
I4	2011	Large	Infrastructure	Other	Crew Catering	-	-
P1	2012	Medium	Total festival	Total festival	Total Festival	-	-
Q2	2012	Major	Stage	Lighting	Main Stage Lighting 2	-	-

Table 116 - Summary values for each system sorted by maximum demand (kW)